Volume 28 MARCH 26, 1953 Number 2

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

NORTH CAROLINA MEETING

AT

DURHAM AND CHAPEL HILL, NORTH CAROLINA

March 26–27–28, 1953

PUBLISHED BY THE AMERICAN PHYSICAL SOCIETY
SIX ISSUES EACH YEAR

BULLETIN

of the

AMERICAN PHYSICAL SOCIETY

Published six times per year

Subscription price: $5.00 per year

Single copies: $1.00 each

The Bulletin of the American Physical Society is published six times a year, once in January, once in March, once in May, once in June, once in November, and once in December, at Prince and Lemon Streets, Lancaster, Pennsylvania.

Entered as second class matter, December 27, 1949, at the post office at Lancaster, Pa., under the Act of August 24, 1912.

Acceptance for mailing at a special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized Nov. 30, 1948.

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NORTH CAROLINA MEETING, MARCH 26–28, 1953

THE **1953 March meeting of the American Physical Society** is designated by the name of a state and not by that of a city, for we are convening at two universities of North Carolina: on Thursday and Friday, March 26 and 27, at Duke University in Durham, on Saturday, March 28, at the University of North Carolina in Chapel Hill. The two communities are about ten miles apart, and arrangements for easy transit between them are being made by the Local Committee.

Several of its groups are joining with the parent Society in this convention. Our Southeastern Section is merging its 1953 meeting with ours, and has arranged a special programme on the teaching of physics. Our Division of Solid-State Physics is abiding by its custom of making this the principal of its meetings during the year, with two Symposia and numerous invited papers. Our Division of High-Polymer Physics has organized a Symposium, has arranged for several invited papers, and has gathered together a number of ten-minute papers. Our Division of Chemical Physics has organized a Symposium on a topic correlated with that chosen by the High-Polymer group.

If number of papers be taken as the measure of the size of a meeting, this will be not only the greatest convention that the Society has ever held in the month of March—it will be the greatest that we ever held elsewhere than in New York, Boston, and Washington (even the Chicago meetings will here be surpassed). This time, and for the first time away from those three cities, the alphabet has not been long enough for denoting the sessions. We shall leave others to dispute how the credit for this amazing inflow is to be distributed among the plans of the Divisions, the plans of the Section, the welcome of the host institutions, and the desirability of seeing North Carolina in the Spring.

The Local Committee, on whose shoulders has fallen this task of quite unexpected size, consists of Messrs. Eugene Greuling (*Chairman*), H. W. Lewis and W. Fairbank of Duke University, and W. A. Bowers and J. W. Straley of the University of North Carolina. From the following pages it will transpire how hard they have been and will be working.

Accommodations. Members are always advised **on the summons card** of the procedure for making reservations, the implication being that they should not await the appearance of the Bulletin (delayed, in this case, by its own great size and by the two holidays in February). On this occasion, those who waited might indeed have missed the boat, were it not that the Local Committee is finding additional space. Those who have yet to act should specify, in their letters, whether they are coming to North Carolina in their automobiles, and, in the cases of men coming alone, whether they are willing to share rooms. These letters should be addressed to the Washington Duke Hotel, Durham, North Carolina; the Local Committee will see them. Do not expect to receive confirmations of any reservations made after March 16.

Access to the Universities. From Main Street in downtown Durham, westbound buses marked "Duke University" or "Duke Hospital" go to the West Campus. Remember that it is the **West** Campus where we are meeting; if the bus you see is marked "Duke University via East Campus" get on it anyhow, but stay on to the end of its route (in front of the Union Building). From Chapel Hill special buses will leave the Carolina Inn between nine and ten on Thursday and Friday mornings; they will bring our members to the Union Building, and take them back from there to Chapel Hill between five and six. On Saturday the buses will go to Chapel Hill from the Washington Duke between nine and ten, and return after the Saturday sessions.

The **registration desk** will be located in the first-floor lobby of the Union Building at Duke University. All members and guests are asked to register, and frequently to consult the nearby

bulletin board for notice of messages. Lists of eating places, maps of the general area, bus schedules, and other useful things will be distributed there.

At this point in the "foretext" of the Bulletin, it is customary to outline the **scientific sessions:** on this occasion, time and space will be saved by referring our readers to the Epitome on page 6 and the "main text" thereafter. But since so much of the programme is dominated by the Divisions, special attention will be directed here to Sessions J, S, and X devoted to molecular spectroscopy, to Session D consisting of invited papers in general physics, to Session M consisting of invited papers in nuclear physics, to Sessions DA and JA pertaining to nuclear physics and cosmic rays, and to Session N (Friday afternoon), which is that of our Southeastern Section. In Sessions U and V some of the speakers were invited by the Division of Solid-State Physics and some by the Society. In the sessions of ten-minute papers on solid-state physics, there are some abstracts which may seem to belong to other sessions than those where they appear: these deviations have been made to conform to special requests, or for some other reason that seemed to justify special treatment. The halls where all the sessions will be held are shown on the maps presented on pp. 52 and 53 of this Bulletin. There are 218 ten-minute papers altogether, twenty-eight of which came to us through the Southeastern Section.

The **banquet of the Society** will be held on Friday evening at seven, in the Main Dining Hall of the Union Building at Duke University. The after-dinner speakers will be Vice-President Paul M. Gross of Duke University, G. B. Pegram, R. J. Seeger, William Shockley, and T. J. Killian: the first three will speak on the National Science Foundation. There will be buses from Chapel Hill, leaving the Carolina Inn between 5:30 and 6:30 and returning after the banquet. The price of the dinner will be $2.60; the tickets will be on sale at the registration desk; the Local Committee requests that they be purchased by 2:00 P.M. on Thursday. Advance reservation should be made by use of the form on the inside back cover page of this Bulletin, since the Duke Union needs to know about how many diners to prepare for.

Entertainment for visiting ladies has been planned on a scale to make the men envious. On Thursday, tours of the two campuses of Duke University, and a visit to the famous Duke Garden, with tea; on Friday, tours of the old Duke homestead and the Chesterfield cigarette factory, and a visit to the campus of the University of North Carolina; on Saturday morning, in Chapel Hill, coffee and a visit to the Morehead Planetarium. Further information at the registration desk!

The **Council of the American Physical Society** will meet at 10:30 A.M. on Thursday in Room 218 of the Physics Building.

Post-deadline ten-minute papers, pertaining to results of very special importance which were not available before the deadline (February 6) for this meeting, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, March 20. The titles of such as are accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session GA. The abstracts will not be published.

Prospective meetings of the Society are scheduled to be held in Washington, D. C., on April 30, May 1–2, 1953; in Rochester, New York, June 18–20; in Albuquerque, New Mexico, September 2–5; and in Chicago, Illinois, November 27–28.

General Rules Relating to Papers

The time allowed for the oral presentation of a contributed paper is ten minutes at most; the time allowed for each invited paper is stated in the Bulletin. When two or more abstracts are submitted by the same author, or by more than one author but with the same name appearing first in the by-line, all but one are printed at the end of the Bulletin, with indication of the conditions under which they may be presented.

Titles and abstracts of the papers contributed to the 1953 North Carolina Meeting are printed hereinafter. They will reappear in *The Physical Review* exactly as they stand in this Bulletin. Errata will be printed on a following page of *The Physical Review* if received not later than Friday April 11 by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, N. Y. Do not send in the abstract marked with corrections: write out the corrections in the form "instead of .....read....." Do not add new material.

Speakers must retrieve their lantern slides before leaving the hall in which these were shown. The Local Committee is under no obligation to save or return them, and should not be expected to do so.

Karl K. Darrow, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Here Is the Summons Card for the 1953 Rochester Meeting

This notice supplants the customary summons card for the 1953 Summer Meeting in the East, to be held in Rochester, New York, on Thursday, Friday, and Saturday, June 18, 19 and 20. Sessions will be held on the River Campus of the University of Rochester. All hotel reservations are to be made by writing (with mention of the Society) to the Hotel Seneca, Rochester, New York; members may be assigned to the Seneca, the Sheraton, or the Powers. It is asked that reservations be made by June 10th; this is no reason for not making them much earlier.

Deadline Will Be Friday, May First

Remember that an abstract may not be longer than 200 words or the equivalent thereof. In reckoning equivalence, a "display" formula (one that occupies a line or more by itself) is equated to 40 words, each line in a table to 10 words, each footnote to 10 words. Send two double-spaced typed copies (original and carbon) of your abstract to the address below, which they must reach not later than Friday, May first. Confine each abstract to a single page; abstracts spread over two pages cost the editors a lot of trouble; an abstract too long to be readily typed on a single page is too long to conform to our rules. It will also help the editors if you will look at the abstracts in this Bulletin, notice in what sequence and in what type (lower case, Roman, italic) the title of the abstract, the author's name, and the author's institution are printed, and prepare your own abstract accordingly.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1953 NORTH CAROLINA MEETING

(Personal names are those of invited speakers, except where they are at the ends of the lines and are names of halls. DHPP stands for Division of High-Polymer Physics, DSSP for Division of Solid-State Physics, and DCP for Division of Chemical Physics.)

DUKE UNIVERSITY

Thursday Morning

A. DSSP: symposium on plasticity and dislocations; Smoluchowski, Read, Fisher. Chemistry 116.
B. Ferromagnetism; magnetic resonance. Engineering 125.
C. Semiconductors, I. Page.
D. Gordy, Townes, London, Rice, Carr. Biology 113.
DA. Nuclear physics and cosmic rays; Palmatier. Physics 114.
DB. DHPP; Bueche. Social Science 117.

Thursday Afternoon

E. Magnetism and ferroelectricity. Engineering 125.
F. DSSP: symposium on semiconductors; Henisch, Shockley, Fan, Miller, Burstein. Page.
G. General physics. Chemistry 116.
GA. Cryogenics. Post-deadline papers, if any. Biology 113.
GB. DHPP: mechanical and electrical properties; Ferry. Physics 114.

Friday Morning

H. DSSP: color centers; Seitz. Page.
I. Metals. Engineering 125.
J. Microwave spectroscopy. Chemistry 116.
JA. Apparatus of nuclear physics. Biology 113.
K. DHPP: symposium on crystallization in polymers; Alfrey, Flory, Mandelkern, Bunn. Physics 114

Friday Afternoon

L. DHPP: continuation of symposium of Session K; Nichols, Boyer, Bunn. Physics 114.
M. Beck, Weinberg, Hereford, Simon, Good. Chemistry 116.
N. Southeastern Section: programme on teaching of physics; Osgood. Page.
O. Mostly about crystals. Engineering 125.
P. Semiconductors, II. Biology 113.

Friday Evening

Banquet of the American Physical Society; Pegram, Gross, Seeger, Shockley, Killian. Main Dining Hall, Duke Union.

UNIVERSITY OF NORTH CAROLINA

Saturday Morning

Q. DCP: symposium on nucleation theory; Turnbull, Hobstetter, Cabrera, Collins. DHPP: Zimm. Howell.
R. Strain and stress; theoretical solid-state physics. Bingham.
S. Infrared spectroscopy. Venable.
T. Effects of irradiation on solids. Phillips.
TA. Business Session of the Southeastern Section. Library, Assembly Room.
U. Beams, Eatherly, Mendoza; Business Meeting of DSSP. Business Administration.

Saturday Afternoon

V. Guinier, Kittel, Callen, Brooks. Business Administration.
W. X-rays; scattering; theoretical physics. Bingham.
X. Ultraviolet spectra; theory of molecular structure; mass-spectroscopy. Venable.
Y. Semiconductors, III. Howell.
Z. Solid-state physics, including diffusion. Phillips.

PROGRAMME

THURSDAY MORNING AT 10:00

Chemistry 116

(CHARLES S. SMITH presiding)

Division of Solid-State Physics

Symposium on Plasticity and Dislocations

A1. The Phenomena of Plastic Flow. R. SMOLUCHOWSKI, *Carnegie Institute of Technology.* (45 min.)
A2. Recent Advances in Dislocation Theory. W. T. READ, *Bell Telephone Laboratories.* (45 min.)
A3. Applications of Dislocation Theory to Plastic Deformation. J. C. FISHER, *General Electric Research Laboratory.* (45 min.)

THURSDAY MORNING AT 10:00

Engineering 125

(J. E. GOLDMAN presiding)

Ferromagnetism; Magnetic Resonance

B1. A Quantum Statistical Mechanics of Ferromagnetism.* RYOICHI KIKUCHI, *M.I.T.*—Heisenberg's model was treated extending the author's treatment of the Ising model. The entropy is approximated as a function of parameters appearing in the density matrix, and the free energy is minimized. The first approximation becomes identical with Yvon's treatment.[1] The second approximations make only three-dimensional lattices ferromagnetic. The high temperature expansion of the partition function gives the first few coefficients of Opechowski's rigorous expansion. Anti-Curie point such as occurred in Weiss' theory does not appear, but the treatment has difficulties near the absolute zero. The above model was extended following Slater's idea[2] so that the overlap integrals can be taken into account. Only one orbital of s type was assumed to be available at each lattice point. Orthogonalized atomic orbitals are used and ionized states are included. The first approximation was formulated and was checked for the simple cubic lattice, in which no ferromagnetic state occurs, confirming Slater's argument.

* Supported by the U. S. Office of Naval Research.
[1] J. Yvon, J. phys. et radium **13**, 488 (1952).
[2] J. C. Slater, Quarterly Progress Report, M.I.T., January 15, 1953, p. 1; H. Statz, *ibid.*, p. 23; see abstract of Slater, Statz, and Koster, Bull. Am. Phys. Soc. **28**, No. 2, B2 (1953).

B2. A Two-Electron Example of Ferromagnetism.* J. C. SLATER, H. STATZ, AND G. F. KOSTER†, *M.I.T.*—We examine the problem of two holes in an otherwise filled band, or two electrons in an empty band, by the method of configuration interaction, using Wannier functions, asking which state lies lower, the triplet or singlet. If the triplet lies lower, it would indicate that the spins set themselves parallel, favoring ferromagnetism. We find that if the band is nondegenerate, the singlet will always lie lower, so that ferromagnetism requires a degenerate band, such as the five-fold degenerate d band. With a degenerate band ferromagnetism results, provided the band is not too broad. The cause of the ferromagnetism is an intra-atomic exchange effect, causing the two electrons or holes to prefer to align themselves with parallel spin when they happen to lie on the same atom. The model leads to a treatment of correlation, showing that with increasing interatomic distance the likelihood of finding the two electrons or holes on the same atom decreases, vanishing at infinite internuclear distance. The ferromagnetic interaction depends on the product of the intra-atomic exchange integral, which persists to infinite distance, multiplied by the probability of finding the electrons or holes on the same atom, which vanishes in the limit.

* Supported in part by the U. S. Office of Naval Research, in part by the Army, Navy, and Air Force.
† Staff member, Lincoln Laboratory, M.I.T.

B3. Electronic Interactions in Ferromagnetic Metals. SOL E. HARRISON, *Remington Rand, Inc.*, AND HERBERT B. CALLEN, *University of Pennsylvania.*—The coupling between d-shells in ferromagnetic metals occurs by direct $d-d$ interaction and also indirectly through the intermediate agency of conduction electrons. Whatever the nature of the direct coupling, the indirect coupling favors ferromagnetic alignment of the d-shells.[1,2] We here propose a model for this indirect interaction with particular reference to nickel. Eight electrons per atom are assumed to be in low-lying d-shells. Above these shells is a broad band of mixed $s-d$ character, containing two conduction electrons per atom and composed of two overlapping sub-bands of opposed spin. The fractional admixture of d-state in each sub-band is governed by the orientation of the low-lying d-shells. The larger admixture, and consequent low energy, occurs for the sub-band with spin opposed to the net magnetization of the low-lying d-shells. Thus the coupling between low-lying d and conduction electrons is antiferromagnetic. The net spin of the conduction electrons is -1.4 magnetons per atom at $T=0$. The predictions of this model with respect to the temperature and magnetization dependence of the resistivity are in good agreement with experimental observations.

[1] C. Zener, Phys. Rev. **81**, 440 (1951).
[2] J. C. Slater, Quarterly Progress Report, M.I.T., January 15, 1953.

B4. Measurement of the Particle Size of Ultrafine Ferromagnetic Powders.* A. D. FRANKLIN, R. B. CAMPBELL, AND J. A. WEINMAN, *Franklin Institute Laboratories.*—The particle size distributions for several ferromagnetic powders with particles in the diameter range from 200 to 800A have been

measured using three techniques. The complete distributions were obtained with the electron microscope. From these distributions the appropriate average sizes, corresponding to the broadening of x-ray diffraction lines and the surface area per gram as measured by nitrogen adsorption, were calculated and compared to the experimental data obtained by these latter techniques. Good agreement was found between the electron microscope and x-ray data, while the nitrogen adsorption method gave somewhat higher values. The over-all agreement obtained supports the validity of the electron microscope distributions.

* This work was supported by the U. S. Office of Naval Research.

B5. The Approach to Saturation in Diluted Ferromagnetic Powders.* A. E. BERKOWITZ AND A. D. FRANKLIN, *Franklin Institute Laboratories.*—As a part of the study of the magnetization processes occurring in ferromagnetic particles dispersed in nonmagnetic media, the approach to saturation of a series of increasingly dilute samples has been measured. The samples were pressed from mixtures of 2 micron carbonyl iron[1] and 50A silicic acid powders, bonded with a suitable resin. At high concentrations of the iron powder, the approach to saturation data agrees with Neel's[2] theory for soft magnetic materials. As the concentration decreases, increasingly large deviations occur. At the extremely dilute end, the main features of the magnetization curve can be accounted for in terms of simple domain theory for weakly interacting particles.

* This work was supported by the U. S. Office of Naval Research.
[1] The carbonyl iron powder used was an experimental material, kindly furnished by the General Aniline and Film Corporation.
[2] L. Neel, J. phys. et radium **9**, 185 (1948).

B6. On Dipolar Anisotropy in Cubic Ferromagnetic Crystals. FREDERIC KEFFER, *University of Pittsburgh.*—The dipolar anisotropy in a cubic ferromagnetic crystal may be obtained from the spin-wave approximation of Holstein and Primakoff.[1] This anisotropy comes from the total spin-wave energy, including zero-point energy, when summed over all values of spin-wave number k. No contribution to this anisotropy comes from $k=0$ spin-waves. Hence, in a ferromagnetic resonance experiment, if only $k=0$ spin-waves were excited, the resonant energy required would be independent of the dipolar anisotropy, in contradiction to the macroscopic theory of Kittel.[2] Terms dropped in the Holstein-Primakoff approximation cause a mixing of spin-waves such that other than $k=0$ waves are excited in resonance experiments. This mixing contributes to spin-spin relaxation[3] and modifies the resonant energy as if a macroscopic dipolar anisotropy field were present.

[1] T. Holstein and H. Primakoff, Phys. Rev. **58**, 1098 (1940).
[2] C. Kittel, Phys. Rev. **73**, 155 (1948).
[3] F. Keffer, Phys. Rev. **88**, 686 (1952).

B7. Thermomagnetic Investigations of Nickel Ferrite-Aluminates.* L. R. MAXWELL, S. J. PICKART, AND R. W. HALL, *U. S. Naval Ordnance Laboratory.*—Trivalent aluminum has been substituted for trivalent iron in nickel ferrite $NiO \cdot Fe_2O_3$ to give the system $NiO \cdot Fe_{(2-x)}Al_xO_3$, where x goes from 0 to 2. The material, annealed and prepared in a powdered form, is a homogeneous spinel with the size of the unit cell (a_0) decreasing linearly from 8.315A to 8.030A as x goes from 0 to 2. The saturation magnetization (σ_s) decreases linearly with increasing x to a minimum at about $x=0.7$; for further increase in x, σ_s increases to a maximum at about $x=1.0$, beyond which it decreases again to zero at $x=2$. Substitution of Al^{+++} for Fe^{+++} at first reduces the resultant moment of the magnetic ions on the B sites (Néel's notation) so that the net moment $(\sigma_s)_B-(\sigma_s)_A$ decreases and tends toward zero. Upon further increase in x the net moment apparently changes sign and increases because of the predominance of $(\sigma_s)_A$ over $(\sigma_s)_B$. Gorter and Herbschleb[1] have also recently found essentially the same effect for the same type of material. The Curie temperature decreases from 560°C to *ca* 50°C as x goes from 0 to 1.5.

* Supported in part by the U. S. Office of Naval Research.
[1] E. W. Gorter (private communication, January, 1953).

B8. Magnetic Resonance Absorption in Nickel Ferrite-Aluminates.* T. R. MCGUIRE, *U. S. Naval Ordnance Laboratory.*—Magnetic resonance measurements were made on small spherical specimens of the nickel ferrite-aluminate compounds at a frequency of 9340 Mc over a temperature range −196°C to +250°C. At −196°C, using the resonance condition[1] $\hbar\omega = g\beta H$, the following g values have been calculated: $x=0$, $g=2.3$; $x=0.25$, $g=2.7$; $x=0.5$, $g=6.9$; $x=0.63$, $g=3.8$; $x=0.75$, $g=1.5$; $x=1.50$, $g=1.5$; where x is the number of Al atoms per molecule $NiOFe_{2-x}Al_xO_3$. The values are seen to shift from $g>2$ to $g<2$ at x approximately 0.7. It is at this same composition that the dominant magnetic moment shifts from the B to the A sites. For samples $x=0.5$ through $x=1$ the g values decrease with increasing temperature. At composition $x=1.75$ and −196°C two resonant peaks were observed, one with $g=1.4$ and a new peak with $g=4.0$. Nickel aluminate ($x=2$) showed no resonance absorption. In most cases the peak heights of the resonance absorption fall off sharply above the Curie temperatures while at low temperatures broadening of the resonance curves was found.

* Supported in part by the U. S. Office of Naval Research.
[1] C. Kittel, Phys. Rev. **73**, 155 (1948).

B9. g Values of the Nickel Ferrite-Aluminates.* ROALD K. WANGSNESS, *U. S. Naval Ordnance Laboratory.*—The resonance frequencies of a system containing two magnetic sublattices having different gyromagnetic ratios γ_1 and γ_2 have been calculated. The resonance condition applicable to a ferrimagnetic sphere is $\omega=\gamma H+\frac{1}{2}\lambda(\gamma_2M_1+\gamma_1M_2)\pm\{\delta H[\delta H-\lambda\times(\gamma_2M_1-\gamma_1M_2)]+\frac{1}{4}\lambda^2(\gamma_2M_1+\gamma_1M_2)^2\}^{\frac{1}{2}}$, where $\gamma=\frac{1}{2}(\gamma_1+\gamma_2)$, $\delta=\frac{1}{2}(\gamma_1-\gamma_2)$, λ is the molecular field coefficient ($\gg$demagnetizing factor), M_1, M_2 are the magnetizations of the sublattices, and $\gamma_i\hbar=g_i\beta$. In first approximation, the resonance frequency is $\omega=\gamma_{eff}H$,[1] where

$$\gamma_{eff}=(M_1+M_2)[(M_1/\gamma_1)+(M_2/\gamma_2)]^{-1}.$$

There is semiquantitative agreement between g values reported in the previous abstract and the calculated values of g_{eff} with respect to their dependence upon the composition of the nickel ferrite-aluminates.

* Supported in part by the U. S. Office of Naval Research.
[1] See N. Tsuya, Prog. Theoret. Phys. **7**, 263 (1952).

B10. Nuclear Resonance Line Shapes at High RF Fields.* W. D. KNIGHT, *University of California, Berkeley.*—The nuclear magnetic resonance absorption and dispersion have been studied in metallic copper for rf fields ranging in magnitude from about 10^{-4} to one oersted. At low values of the rf field the line width is primarily dipolar,[1] except for a small spin-lattice relaxation broadening,[2] and the shape is approximately Gaussian. As the value of the rf field is increased toward one oersted, which is about twice the value necessary to make the saturation parameter equal to unity, the line width between maximum slope of the absorption curve increases from 6.5 to 7.5 oersteds. The dispersion curve broadens in a similar fashion. From the saturation of the absorption and a measurement of the rf field, a spin-lattice relaxation time of approximately one millisecond is calculated. This agrees reasonably with an extrapolation of Bloembergen's result to room temperature, and also with the result obtained from Korringa's formula and the measured line shift.[2] The shapes of the curves during saturation will be discussed. We wish to thank Dr. Carson D. Jeffries for making his nuclear induction spec-

trometer with rf field calibration available for use in these studies.

* Supported in part by the U. S. Office of Naval Research.
[1] H. S. Gutowsky and B. R. McGarvey, J. Chem. Phys. **20**, 1472 (1952).
[2] N. Bloembergen, Physica **15**, 588 (1949); J. Korringa, Physica **16**, 601 (1950).

B11. Saturation of the Paramagnetic Resonance from Color Centers in Alkali Halides.* A. M. PORTIS AND A. F. KIP, *University of California, Berkeley.*—Saturation of the paramagnetic resonance signal in dilute samples of additively colored KCl and KBr has been observed in the 9000 Mc/s region. We find that over a range of 20 db in microwave field, χ' is essentially constant but χ'' is inversely proportional to the magnitude of the microwave field. To within the accuracy of our measurements we observe no change in the width of the absorption or dispersion. We are unable to account for this saturation behavior on the basis of a simple two-level model for the resonance absorption where the width of the levels is ascribed to dipole-dipole interaction. However, if we assume that the over-all resonance line is a superposition of much narrower lines dispersed by an interaction external to the spin system, such as hyperfine interaction, we can account for the observed saturation behavior. A saturation in which only the absorption is affected would seem to be in conflict with the Kramers-Kronig relations. However, as will be shown, the Kramers-Kronig relations in their usual form are valid only in the absence of saturation.

* Supported in part by the U. S. Office of Naval Research.

THURSDAY MORNING AT 10:00

Page Auditorium

(R. G. BRECKENRIDGE presiding)

Semiconductors, I.

C1. Radiationless Trapping of Charge Carriers in Solids. GREGORY H. WANNIER, *Bell Telephone Laboratories.*—It is well known that transitions arising from coupling with the sound field are generally more probable for electrons and holes in solids than radiative transitions. Thus, electrons are trapped in a region of negative potential energy probably by phonon emission. If this is true, then we may tentatively define the trapping probability as the probability of emitting a phonon of such a type as to bring the electron into a negative energy state. This definition yields a trapping cross section which varies violently with electron energy. If the electron moves with twice the velocity of sound, the cross section is essentially infinite, while, for thermal electrons, the cross section is 10^{-16} cm^2 or less. In view of this we may calculate an upper limit for the trapping rate by assuming that all slow electrons are trapped and that the process is limited by the rate at which thermal electrons are slowed down to the speed of sound. For Si this rate comes out to be 10^9 sec^{-1} at room temperature and varying as $T^{-\frac{1}{2}}$. For Ge it is smaller; this may be one of the reasons why it is harder to observe trapping in germanium than in silicon.

C2. Carrier Contribution to the Dielectric Constant of Germanium. T. S. BENEDICT AND W. SHOCKLEY, *Bell Telephone Laboratories.*—The dielectric constant of germanium ($\rho = 5-40$ ohm cm) was measured as a function of temperature using 1.24-cm microwaves.[1] The results were compared with the following formula (M.K.S.):

$$\kappa = \kappa_0 - \frac{Ne^2\tau^2}{\epsilon_0 m^*[1+(\omega\tau)^2]},$$

which is obtained essentially by the method used in the Drude-Zener theory[2] assuming an effective mass m^* and unique relaxation time τ for the carriers. Since the dc conductivity and mobility[3] are known m^* and τ may be deduced. Preliminary results show that $m^* \simeq 0.6 m_0$ for n type and 1.1 m_0 for p type germanium. The relaxation time is then given by $6.6\times10^{-9}T^{-1.5}$ for n type and $6.6\times10^{-7}T^{-2.3}$ for p type germanium in the temperature range 160°K to 298°K.

[1] Dielectric measurements have recently been made on germanium at room temperature using 10-cm microwaves. [J. M. Goldey and S. C. Brown, Bull. Am. Phys. Soc. **28**, No. 1, A7 (1953)].
[2] See for example F. Seitz, *Modern Theory of Solids* (McGraw-Hill Book Company, Inc., New York, 1940), Sec. 147.
[3] Drift mobilities of holes and electrons in germanium have recently been measured by M. B. Prince. These values were used in the interpretation of the results.

C3. Diffusion Currents in the Hall Effect in Semiconductors. ROLF LANDAUER AND JOHN SWANSON, *I.B.M.*—The usual Hall effect equation for semiconductors, $eRc = (p-nb^2)/(p+nb)^2$, holds if the concentration of carriers is undisturbed. In a magnetic field, however, holes and electrons are swept to the same side of the conductor. A gradient of carrier concentrations is thereby established, giving rise to diffusion currents across the sample. The magnitude of the diffusion currents depends on the recombination velocity at the surface and on the lifetime of excess carriers in the interior. When recombination is rapid, departures from equilibrium concentrations are small, and the ordinary formula applies. When recombination is absent, the correct equation becomes $eRc = (p-bn)/(n+p)(nb+p)$. Fowler[1] has derived the latter formula, and Welker[2] has treated another special case. It is desirable, however, to have more general formulas, since discrepancies in the Hall effect for samples having identical carrier concentrations may then be correlated with the lifetimes for these samples. Accordingly, the dependence of the Hall voltage on lifetime has been calculated for several geometries.

[1] R. H. Fowler, *Statistical Mechanics* (Cambridge University Press, Cambridge, England, 1936).
[2] H. Welker, Z. Naturforsch. **6a**, 184 (1951).

C4. Current Carrier Mobility Ratio in Semiconductors. L. P. HUNTER, *I.B.M.*—The ratio of the electronic mobility to the hole mobility in germanium has been reported by many workers. The value 1.5 is reported by those deducing the ratio from Hall effect measurements, while those using drift techniques find the value 2.0.[1] In both cases the ratio reported is usually obtained by measurements on two different samples of different conductivity types. The method suggested here deduces the mobility ratio from resistivity measurements made on a single sample. An accurate plot of resistivity as a function of temperature is made. The extrinsic and intrinsic branches of this curve are extrapolated to their intersection. If r is defined as the ratio of the resistivity of this intersection point to the measured resistivity at the same temperature, the quantity $[(1/r-1)-r]$ gives the mobility ratio for P type samples, and its reciprocal for N type samples. Values obtained by Dr. Huibregtse of this laboratory using this method agree well with the value 2.0 obtained by drift measurements near room temperature.

[1] W. Shockley, *Electrons and Holes in Semiconductors* (D. Van Nostrand Company, Inc., New York, 1950), p. 337.

C5. Current Carrier Lifetimes Deduced from Hall Coefficient and Resistivity Measurements. E. J. HUIBREGTSE AND L. P. HUNTER, *I.B.M.*—As a result of the theory of R. Landauer and J. Swanson,[1] a family of curves, having carrier lifetime as parameter, may be calculated to relate certain Hall coefficient and resistivity measurements to the current carrier mobility ratio. A convenient function to use for this purpose is the ratio of the intrinsic Hall mobility to the extrinsic Hall mobility extrapolated to a common temperature. With such a set of parametric curves the lifetime is determined if the two coordinates (Hall mobility ratio and carrier mobility ratio) are known. On a single sample both resistivity and Hall coefficient may be measured simultaneously as functions of temperature. The Hall mobility ratio may be calculated directly, and the mobility ratio may be determined from the resistivity curve as outlined by L. P. Hunter.[2] In this way, current carrier lifetimes may be measured without recourse to carrier injection techniques.

[1] R. Landauer and J. Swanson, Bull. Am. Phys. Soc. **28**, No. 2, C3 (1953).
[2] L. P. Hunter, Bull. Am. Phys. Soc. **28**, No. 2, C4 (1953).

C6. Temperature Variation of Drift Mobilities of Minority Carriers in Semiconductors. M. B. PRINCE, *Bell Telephone Laboratories.*—Experimental data of drift mobilities of electrons in p type germanium and silicon are brought into agreement with theoretical predictions by distinguishing between group velocity and particle velocity of a pulse of minority carriers. Corrected high temperature measurements of electron drift mobility are consistent with the theoretical prediction $\mu = AT^{-\frac{3}{2}}$. The experimentally determined values of A are

$$2.0\times10^{7}\ \text{cm}^2\ \text{deg}^{\frac{3}{2}}/\text{volt-sec for germanium}$$

and

$$0.62\times10^{7}\ \text{cm}^2\ \text{deg}^{\frac{3}{2}}/\text{volt-sec for silicon.}$$

Corrected high temperature measurements of hole drift mobility are consistent with the equation $\mu = BT^{-2.3}$. The experimentally determined values of B are

$$9.1\times10^{8}\ \text{cm}^2\ \text{deg}^{2.3}/\text{volt-sec for germanium}$$

and

$$2.5\times10^{8}\ \text{cm}^2\ \text{deg}^{2.3}/\text{volt-sec for silicon.}$$

At present there is no explanation for the anomalous value of 2.3 in the experimental equation for the hole drift mobility.

C7. Mobilities of Carriers in Crystalline Boron. WM. C. SHAW, D. E. HUDSON, AND G. C. DANIELSON, *Iowa State College.*—Microscopic single crystals of boron have been studied using procedures previously described.[1] Conductivity, Hall, and thermoelectric measurements were made on two low resistivity n type specimens and one high resistivity p type specimen. A statistical treatment allowed determination of small Hall voltages superimposed on noise fluctuations. An n type crystal having a resistivity of (61 ± 12) ohm-cm at 25°C had a Hall coefficient of about -400 cm³/coulomb indicating an electron mobility near 7 cm²/volt sec. The Hall coefficient of this crystal changed sign at higher temperatures. Another crystal, which exhibited at 25°C properties characteristic of an intrinsic semiconductor, had a resistivity of $(1.7\pm0.3)\times10^{6}$ ohm-cm at 25°C. Its Hall coefficient was approximately $+3\times10^{15}$ cm³/coulomb. These data indicate that the mobility of holes slightly exceeds that of electrons. One low resistivity crystal had a thermoelectric power of about -300 microvolts/degree near room temperature; the thermoelectric power changed sign at about 265°C and finally reached the order of 500 microvolts/degree near 600°C. This change of sign indicates that the hole mobility exceeds the electron mobility, in agreement with the results of the Hall measurements.

[1] Shaw, Hudson, and Danielson, Phys. Rev. **89**, 900 (A) (1953).

C8. Hall Effect and Conductivity of Germanium Containing Arsenic or Gallium as Impurities. PETER P. DEBYE,* *Bell Telephone Laboratories.*—Samples of highly purified germanium to which varying amounts of arsenic or gallium had been added were measured by a dc method from 11 to 300 degrees absolute. Room temperature conductivities ranged from 200 to 0.024 $(\text{ohm cm})^{-1}$ for samples containing arsenic and from 110 to 0.033 $(\text{ohm cm})^{-1}$ for those containing gallium. For low concentrations, donor as well as acceptor impurities showed ionization energies of approximately 0.01 electron volts. The Hall mobility at 300 degrees absolute in high resistivity samples was found to be 4400 cm²/volt sec for electrons and 3500 cm²/volt sec for holes.

* Now at Raytheon Manufacturing Company, Waltham, Massachusetts.

C9. Electrical Properties of n type Germanium.* ESTHER M. CONWELL,† *Sylvania Electric Products Inc.*—Experimental results for carrier concentration and Hall mobility obtained by P. P. Debye for a set of n type germanium samples have been compared with theory. Plots of Hall mobility *vs* resistivity at constant temperature were used to check the theoretical formulas for ionized and neutral impurity scattering and, in particular, to obtain approximate values for the effective mass at various temperatures. An over-all value in the neighborhood of one-quarter the free electron mass is indicated, but this may vary considerably with temperature in this range. The effect of electron-electron collisions on the mobility was considered and in a qualitative way included in the analysis. Curves of $\log_e$ of carrier concentration *vs* the reciprocal of absolute temperature were fitted to obtain values of the activation energy and concentration of acceptors in these samples. The latter are compared with the values computed from the 11.5°K values of the mobility.

* Work done partly at Bell Telephone Laboratories.
† On leave from Brooklyn College.

C10. Acceptor States of Gold in Germanium. W. C. DUNLAP, JR., *General Electric Research Laboratory.*—A number of single-crystal ingots of germanium, doped with high purity gold from three separate sources, have been prepared. It was found in most cases that addition of gold increased the resistivity of n type material, and in several cases the gold-doped portions were p type. Hall effect measurements were made between 77°K and 400°K. Many of the samples were intrinsic at temperatures as low as 0°C, whereas adjacent wafers from the "undoped" portion were usually in the range 1–20 ohm cm at room temperature. At 77°K most samples had resistivities of the order of 10^6 ohm cm. The carriers, for n type samples, had activation energies about 0.18 ev; for p type samples, about 0.15 ev. It is suggested that gold produces acceptor states at various levels in the forbidden region, the highest being 0.18 ev from the conduction band, the lowest about the same distance from the filled band. The properties of the germanium, including type, resistivity, and observed activation energy, are determined by the relative concentrations of the gold-levels and ordinary impurity states.

C11. Broadening of Impurity Levels in Silicon. M. LAX, *Syracuse University*, AND E. BURSTEIN, *Naval Research Laboratory.*—Electrons or holes trapped at an impurity center in a homopolar material move in hydrogen-like orbits that are disturbed by lattice vibrations. Using the Franck-Condon principle, the broadening of the absorption spectrum can be calculated if the energy of the trapped electron is known as a function of the nuclear coordinates.[1] An estimate of the electron energy dependence on lattice coordinates can be made by treating the electron-lattice interaction as a small perturbing energy. The unperturbed electronic state is expressed as a linear superposition of orthogonalized atomic orbitals. By

reformulating the latter in terms of Block orbitals, the first-order perturbation expression for the energy can be re-expressed in terms of the usual matrix elements that occur in the theory of electrical conductivity. The *form* of these matrix elements is known approximately from the Bardeen-Shockley deformation potential method. The normalizing multiplicative constant is determined by the experimental high temperature mobility. Thus a prediction of the broadening of the absorption spectrum as a function of temperature is made from first principles. A comparison between theory and experiment will be given.

[1] M. Lax, J. Chem. Phys. **20**, 1752 (1952).

THURSDAY MORNING AT 10:00

Biology 113

(W. M. NIELSEN presiding)

Invited Papers

D1. One-to-Two-Millimeter Wave Spectroscopy. W. M. GORDY, *Duke University.* (30 min.)

D2. Some Recent Developments in Microwave Spectroscopy. C. H. TOWNES, *Columbia University.* (30 min.)

D3. On the Theory of Liquid Helium. FRITZ LONDON, *Duke University.* (30 min.)

D4. Thermodynamics of Stationary Helium Films. O. K. RICE, *University of North Carolina.* (30 min.)

D5. Negative Ions in the Gaseous Phase. H. E. CARR, *Alabama Polytechnic Institute.* (30 min.)

THURSDAY MORNING AT 10:00

Physics 114

(C. K. BECK presiding)

Nuclear Physics and Cosmic Rays

Contributed Papers

DA1. The Hyperfine Structure and Nuclear Moment Ratios of the Stable Bromine Isotopes.* J. G. KING AND V. JACCARINO, *M.I.T.*—The hyperfine structure of the $^2P_{\frac{1}{2}}$ state of atomic Br^{79} and Br^{81} has been investigated by the atomic-beam magnetic-resonance method. The ratio of the magnetic dipole interaction constants a^{81}/a^{79} is 1.07794 $\pm$0.00001, and the ratio of the electric quadrupole interaction constants b^{79}/b^{81} is 1.19707$\pm$0.00003. Applying the results of recent theoretical calculations by Sternheimer,[1] Koster,[2] and Feld, the following values of nuclear quadrupole moments were computed:

$$Q^{79}=0.335\times10^{-24}\ \text{cm}^2 \quad Q^{81}=0.280\times10^{-24}\ \text{cm}^2.$$

* This work was supported in part by the Signal Corps, the Air Materiel Command, and the U. S. Office of Naval Research.

[1] R. Sternheimer, Phys. Rev. **86**, 316 (1952).

[2] G. F. Koster, Phys. Rev. **86**, 148 (1952).

DA2. Alpha-Particle Straggling in Thin Foils.* P. T. PORTER AND J. I. HOPKINS, *Vanderbilt University.*—Alpha-particles of 5.3 Mev from Po were used to bombard various thicknesses of aluminum, copper, and gold foil. The energy spectra of the emergent alpha-particles were then determined with a scintillation spectrometer using anthracene as the detection crystal. Differential curves of counting rate *versus* energy give the well-known Gaussian distribution; however, a very pronounced tail is found toward the lower energies. The presence of the tail is explained by the fact that a large fraction of the particle's energy can be lost in a single collision. The extent to which the shape and size of this tail is dependent upon the most probable energy of the emergent particles is investigated according to the method developed by Lewis.[1] How the energy distributions differ from a Gaussian for the different absorbers and absorber thicknesses will be discussed.

* Work supported by U. S. Atomic Energy Commission.

[1] H. W. Lewis, Phys. Rev. **85**, 20 (1952).

DA3. Neutron Resonances in Bi, Tl, and Pb. J. H. GIBBONS AND HENRY W. NEWSON, *Duke University.*—Li(p, n) neutrons emerging at an angle of 120° to the proton beam have been used to measure the total cross sections of the heaviest stable nuclides. The resolving power is about 1 kev at 10 kev and somewhat poorer at lower and higher energies. The previously reported resonance in Bi at 2.5 kev has been confirmed, and six more typical scattering resonances have been found at 13, 16, 34, 46, 60, and 68 kev. These numbers are subject to revision after recalibration of the magnetic analyzer. The transmission curve shows evidence for many more poorly and partially resolved resonances. The average level separation appears to be considerably less than 10 kev. Our resolving power has been insufficient so far to find a well-resolved resonance in Tl, but nonstatistical fluctuations in the transmission curve indicate weak resonances spaced about 1 kev apart. The results on Pb are similar to those on Tl. These elements will be investigated with higher resolving power.

DA4. A Ranger Study of the Po-Be Neutron Spectrum.* HERBERT GURSKY, BARBARA WINNEMORE, AND D. A. COWAN, *Vanderbilt University.*—The Ranger,[1] a variable absorption, proportional counter arrangement for the counting of heavy particles of selected species and energies, has been applied to study the neutron spectrum of a homogeneously mixed Po-Be source. For the measurement the source, which had an initial

intensity of 3.28×10^7 neutrons per second, was suspended four inches from a paraffin radiator and the spectrum measured over an energy range from 2.6 to 8.6 Mev. Individual points in the spectrum have been determined with a statistical accuracy of about one percent. The detector, an aluminum foil of 7.15 mg/cm² thickness, gave a resolution of about 0.5 Mev. The spectrum presents broad maxima at 3.2 and 5.5 Mev and a sharp peak at 4.6 Mev with an average neutron energy of 4.68 Mev. These results are consistent with data published by Whitmore and Baker.[2]

* Work supported by the U. S. Atomic Energy Commission.
[1] David L. Hill, U. S. Atomic Energy Commission Report AECD, 1945.
[2] B. G. Whitmore and W. B. Baker, Phys. Rev. **78**, 799 (1950).

DA5. The Average Energy of the Beta-Rays of P^{32} and Ag^{111}. J. M. Brabant,* L. W. Cochran, and R. S. Caswell,* *University of Kentucky.*—Utilizing an extrapolation ionization chamber and 4π methane-flow proportional counter technique, the average energy per disintegration $\bar{E}$ of the beta-rays of P^{32} and Ag^{111} has been measured. The extrapolation chamber is used to determine the energy liberated per gram per second E_t of the beta-radioactive medium, and the 4π counter is used to determine the disintegration rate per gram n of the medium. Then $\bar{E}$ is found from the relation, $\bar{E}=E_t/n$. The P^{32} determinations indicate $\bar{E}=0.694\pm0.025$ Mev per disintegration, a value in good agreement with previous results. The value, $\bar{E}=0.376\pm0.014$ Mev per disintegration, obtained for Ag^{111} includes a correction for the gamma-radiation present. A numerical and graphical evaluation of the theoretically expected value for the branched spectra of Ag^{111} gives $\bar{E}=0.382$ Mev per disintegration, a value in close agreement with the observed value. Both experimental determinations include a correction for bremsstrahlung.

* Now at the National Bureau of Standards, Washington, D. C.

DA6. Beta-Ray Spectra of C^{14} and Ni^{63}.† J. P. Mize and D. J. Zaffarano, *Iowa State College.*—The beta-ray spectra of C^{14} and Ni^{63} have been investigated with a 4π geometry proportional counter spectrometer[1] using internal solid radioactive sources. A C^{14} source of high specific activity was prepared in the form of α-hydroxyglutaric acid, $C_5{}^*H_8O_5$, uniformly labeled. A Ni^{63} source of considerably lower specific activity was prepared from Ni^*Cl_2. The estimated average surface densities of these two water soluble sources were: C^{14}, 11 μg/cm² and Ni^{63}, 50 μg/cm². The end point of C^{14} was in good agreement with previous measurements.[2] but the Fermi plot of the data was concave toward the energy axis below 50 kev. The end point of Ni^{63} was in good agreement with a previous measurement;[3] however, the Fermi plot was concave toward the energy axis below 30 kev. The negatron distributions of these nuclides will be presented and compared with the spectra of S^{35} and Pm^{147} as measured with our spectrometer, which yielded linear Fermi plots to 10 and 15 kev, respectively.

† This work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
[1] J. P. Mize and D. J. Zaffarano, Phys. Rev. **89**, 902(A) (1953).
[2] S. D. Warshaw, Phys. Rev. **80**, 111 (1950).
[3] H. M. Wilson and S. C. Curran, Phil. Mag. **40**, 63 (1949).

DA7. Angular Distribution of 12 Mev Gamma-Rays from the Proton Bombardment of Boron.* G. L. Jenkins, L. W. Cochran, H. H. Givin, J. L. Ryan, T. M. Hahn, and B. D. Kern, *University of Kentucky.*—The angular distribution of the 12 Mev gamma-rays from proton bombardment of thick boron targets has been obtained in the energy region between 200 kev and 800 kev. Results indicate an angular distribution with respect to the proton beam of the form $Y(\theta)=1+A\cos\theta+B\cos^2\theta$. $A=0$ at 180 kev, and $A=0.10\pm0.02$ in the energy region between 300 kev and 800 kev. $B=0.25\pm0.03$ at 180 kev and 300 kev, and $B=0.05\pm0.02$ in the energy region between 400 kev and 800 kev. The $\cos\theta$ term implies interference between levels of opposite parity.

* Supported by Office of Ordnance Research, Army Ordnance Corps.

DA8. Fission Cross Section of Uranium-234. R. W. Lamphere, *Oak Ridge National Laboratory.*—The neutron-induced fission cross section of U-234 has been measured from threshold to 4-Mev neutron energy, using the $T(p, n)$ reaction with a tritium gas target, and the Oak Ridge 5-Mev Van de Graaff. The curve rises from threshold at 350 kev to 1.33 barns at 4 Mev. There is a minimum at 1.08 Mev and another at 2.30 Mev. The shape of the curve is believed to be good to 3 percent; but the ordinate scale factor is in doubt to 14 percent because of uncertainty in the weight of material on the foils. Enough counts were taken in the region of the two minima to establish their reality to a probability of a billion to one relative to a "best fit" curve with no extremes.

DA9. Phenomenological Interpretation of π^+ Meson Production by Protons on Carbon. M. M. Block, *Duke University,* S. Passman, *Hughes Research and Development Laboratories,* and W. W. Havens, Jr., *Columbia University.*—A phenomenological calculation of π^+ meson production by protons on carbon, at various laboratory angles and proton bombarding energies, has been carried out under the following assumptions: (1) meson production occurs in nucleon-nucleon collisions; (2) the π^+ meson is produced with the maximum possible kinetic energy in the center-of-mass system; (3) the internal momentum distribution of the nucleons before collision is Gaussian, corresponding to an average energy of 19.3 Mev; (4) the excitation for π^+ production in a nucleon-nucleon collision in a heavy nucleus is the same excitation function as for the reaction $p+p\rightarrow\pi^++d$. The excitation function employed for meson production in an elementary collision was taken from experiment[1] and is essentially given by a T^2 law, where T is the maximum meson energy in the center-of-mass system. The results will be applied to recent experimental results.[1,2]

[1] Passman, Block, and Havens, Phys. Rev. **88**, 1247 (1952).
[2] W. F. Dudziak, Bull. Am. Phys. Soc. **28**, No. 1, D4 (1953).

DA10. Star Clustering in Nuclear Emulsions. Frank B. Brown, Jr., and A. V. Masket.—A study has been made of the distribution of nuclear stars in photographic emulsions which were exposed for 6½ hours at 84 000 feet. The number of close pairs of stars has been found to exceed greatly the number which would be predicted on the basis of a random distribution. All possible spurious effects which might cause this anomaly to appear have been eliminated or taken into consideration. The effect is shown to depend upon the larger stars of six or more prongs. A tentative explanation of the above effect is given, which involves the passage through the emulsion of narrow showers of high energy particles. These particles create large stars in the emulsions in a non-random array, and it is this array, superimposed on a background of randomly placed stars, which produces a statistical surplus of close pairs. Corroborative evidence for this mechanism is (a) the relative surplus of larger stars found on the plates, (b) the collimation of incident particles for star "clusters" which are assumed to be shower produced, and (c) the greater number of tracks which are observed in the vicinity of such a "cluster," compared with the number found in an isolated region.

Invited Paper

DA11. Ionization Energy Losses of Mu-Mesons in Gases. E. D. Palmatier, *University of North Carolina.* (30 min.)

THURSDAY MORNING AT 10:00

Social Science 117

(L. A. WOOD presiding)

Division of High-Polymer Physics

Invited Paper

DB1. The Reinforcement of Silicone Rubber. A. M. BUECHE, *General Electric Research Laboratory.* (20 min.)

Contributed Papers

DB2. Sedimentation Rates in Dilute and Moderately Concentrated Polymer Solutions. M. WALES (introduced by S. G. Weissberg).—This work is the initial step in an effort to correlate sedimentation rates of chain polymers on a general basis as a function of concentration, solvent, and molecular weight. It is hoped that the conclusions so obtained can be used to deduce information about chain configuration in concentrated solutions. Darcy constants[1] of polystyrene solutions up to 10 percent by weight have been obtained as a function of concentration for polystyrene fractions in butanone and toluene. Empirical equations, which represent the sedimentation behavior over the whole range studied have been devised. The constant K_s, which describes the dependence of sedimentation constant on concentration in dilute solutions, has been found to be 1.7 times the intrinsic viscosity. This relationship is valid with good precision for polystyrene in chloroform, butanone, and toluene, for polyisobutylene in cyclohexane, and for polymethylmethacrylate in acetone. These systems comprise all the data examined, from the literature, and from this work. This proportionality was first noticed experimentally for polystyrene in a number of solvents by Newman and Eirich.[2] It is apparently more generally valid than was originally supposed.

[1] R. Signer and H. Egli, Rec. Trav. Chim. **64**, 45 (1950).
[2] S. Newman and F. Eirich, J. Colloid Sci. **5**, 541 (1950).

DB3. Nucleoprotein Monolayers. ADOLPH B. AMSTER* AND QUENTIN VAN WINKLE, *The Ohio State University.*—A sensitive Wilhelmy apparatus for the study of nucleoprotein monolayers has been constructed. Film pressures may be read to 0.12 dyne/cm and estimated to 0.003 dyne/cm. It was found that rabbit appendix nucleoprotein spread as a gaseous film upon aqueous substrates of *p*H 5 to 9 and ionic strength 0.14 and 1.00. The extent of spreading and the number-average molecular weight were found to be a function of the mass of material spread. From these results it was found that the cross section per molecule was 4.4×10^4 sq A. The molecular weight varied from 2.66×10^6 at an initial spreading concentration of 4.27 mg/meter[2] to 0.24×10^6 at an initial spreading concentration of 0.458 mg/meter.[2] Certain apparent anomalies in the low pressure region are explained. An hypothesis is offered to explain the variations of molecular weight with spreading concentration, coupled with the invariant cross section. The nucleoprotein dissociates and unfolds in a manner dependent upon the surface concentration. This process appears to be irreversible and unchanging.

* Present address: National Bureau of Standards.

DB4. The Dependence of the Photoelastic Properties of GR-S on the Degree of Cross Linking.* G. R. TAYLOR AND S. R. DARIN, *Mellon Institute* (introduced by R. S. Marvin).—The birefringence *vs* stress relationship for decamethylene dis-methylazodicarboxylate vulcanizates of GR-S has been determined as a function of the degree of cross linking. The experimental results show a systematic deviation from Brewster's law (stress proportional to birefringence) at stresses greater than 30 kg/cm², the deviations becoming more pronounced as the degree of cross linking is decreased. While most of the measurements were taken during stress relaxation, in the cases where it was possible to obtain approximately equilibrium conditions, it was found that the stress-birefringence ratio was essentially independent of the state of relaxation of the material, i.e., relaxation occurs along the equilibrium stress-birefringence curve. In the light of these results, the applicability of W. Kuhn's[1] expression for birefringence/stress is discussed, and reasons for its failure in light vulcanizates are suggested.

* This work was supported by the Office of Synthetic Rubber, Reconstruction Finance Corporation.
[1] W. Kuhn and F. Grün, J. Polymer Sci. **1**, 183 (1946).

DB5. Stress Crazing Thresholds of Methyl Methacrylate Polymers. T. F. PROTZMAN, J. J. GOUZA, AND W. F. BARTOE, *Rohm & Haas Company.*—Time-deformation studies have been made on stressed cantilever beams of polymethyl methacrylate. The first incidence of crazing on each beam was observed. From the deformation a measure of the strain in the outer fibers of the cantilever beam is calculated at the time of incidence of crazing. It is found that the crazing threshold strain is a linear function of the applied stress. This contrasts with the results obtained by Maxwell and Rahm,[1] who found that polystyrene crazes at a fixed strain. The results of those measurements are interpreted qualitatively on a basis of polymer rheology.

[1] B. Maxwell and L. F. Rahm, Princeton University, Plastics Laboratory Technical Report 11B, September 21, 1948.

DB6. Values of Diffusion Coefficients for Some Chain Polymers Computed from Anomalous Osmotic Pressure Data. T. A. BARR, JR., *University of Georgia.*—In order to explain the anomalous osmotic pressures reported by Matthews[1] and the author,[2] it was necessary to establish a model osmometer into which the solvent flowed under a pressure difference equal to the difference between the theoretical osmotic pressure and observed osmotic pressure, and out of which the solute diffused by virtue of the concentration gradient across the osmometer membrane. Under the condition that the volume of solution be held constant in the model osmometer, an equation has been established which relates the theoretical osmotic pressure, the observed osmotic pressure, and the diffusion coefficient for the solute. The evaluation of a series of diffusion coefficients for a "family" of chain polymers has been made, and a comparison given between these values and those obtained by other observers for the free diffusion of various chain polymers, and for computed values of the diffusion coefficients for prolate spheroids.

[1] D. E. Matthews, "A study of the semipermeability of silver membranes" (unpublished Ph.D. dissertation, Department of Physics, Vanderbilt University, 1951).
[2] T. A. Barr, "Anomalous osmotic pressures of polymer solutions as measured in a metal membrane osmometer" (paper presented at the APS Southeastern Section Meeting, 1952).

THURSDAY AFTERNOON AT 2:00

Engineering 125

(C. G. SHULL presiding)

Magnetism and Ferroelectricity

E1. Magnetic Properties of Pyrrhotite. ROBERT R. HEIKES, *Westinghouse Research Laboratories.*—An explanation of the unusual magnetic properties of Fe-S has recently been given by L. Néel.[1] He proposes that the off-stoichiometric compounds (sulfur rich) are really ferrimagnetic. An alternate explanation will be offered in which the dominant interaction is assumed to be the double exchange of Zener.[2] The present model is also able to account for the unusual properties of Cr-S, a compound with the same structure as Fe-S, whereas the picture presented by Néel apparently fails.

[1] L. Néel, Washington Magnetism Conference (1952).
[2] C. Zener, Phys. Rev. **82**, 403 (1951).

E2. Field and Temperature Dependence of the De Haas-Van Alphen Effect in Zinc Alloy Single Crystals.* F. J. DONAHOE, *University of Pennsylvania.*†—The differential magnetic susceptibilities of zinc alloy single crystals have been measured by a torsion method in uniform magnetic fields in the range 2000–9500 oersteds at temperatures between 1.5 and 20.4°K. The results have been compared with a function of the form given by the theory of the diamagnetism of free electrons[1–4] using the electron mass m^*, Fermi level ζ, and the mean free time τ between electron collisions as adjustable parameters:

$$\chi(\mu_0^* H) = -\frac{\mu_0^2 k T \zeta}{2\pi\rho\hbar^3}\left(\frac{2m}{\mu_0 H}\right)^{\frac{1}{2}} \sum_{r=1}^{\infty} \frac{(-1)^r \cos\left(r\pi\frac{m^*}{m}\right)\sin\left(\frac{r\pi\zeta}{\mu_0^* H}-\frac{\pi}{4}\right)}{r^{\frac{1}{2}}\sinh\left(\frac{r\pi^2 kT}{\mu_0^* H}\right)\exp\left(\frac{r\pi\hbar}{\tau\mu_0^* H}\right)}.$$

The approximate form of the first term of the series expansion is a poor fit. Harmonic terms are important at high fields. Satisfactory agreement is found for the temperature dependence. Discrepancies in the field dependence suggest that the exponent of the factor $1/H$ which multiplies the series is 5/2 rather than 3/2 as predicted by the free electron theory.

[1] D. Shoenberg, Proc. Roy. Soc. (London) **A170**, 341 (1939).
[2] E. H. Sondheimer and A. H. Wilson, Proc. Roy. Soc. (London) **A208**, 173 (1951).
[3] R. B. Dingle, Proc. Roy. Soc. (London) **A211**, 500 (1952).
[4] M. C. Steele, Phys. Rev. **88**, 451 (1952).
* Supported by the U. S. Atomic Energy Commission.
† Now at The Franklin Institute Laboratories.

E3. The de Haas-van Alphen Effect in Sn-Sb Alloys.* GEORGE T. CROFT† AND FOSTER C. NIX, *University of Pennsylvania.*—The de Haas-van Alphen effect has been observed in tin and in tin antimony alloys at field strengths less than 10 (kg). Particular care was taken to control the composition and thermal equilibrium state of the alloys. The electronic parameters, β and ζ, associated with the long period oscillations are not affected, within the limits of experimental error (±10 percent), by the addition of Sb into the Sn lattice. The collision broadening parameter, X, increases linearly with atomic percent of solute atoms. X for pure Sn ($\simeq$0.1°K) is a factor of 10 less than values quoted by Shoenberg.[1] This is attributed to the careful handling and heat treatment given the samples. A marked angular dependence of X was noted in two of the alloy samples. The results indicate that X increases with the angle between the tetragonal axis and the field. There is evidence that the dependence of the amplitude on H is actually given by a higher power of H^{-1} than ½. These data were obtained using a new technique, which enables one to measure continuously the torque on a sample as a function of the field.

* Supported by the U. S. Atomic Energy Commission.
† Now at the Edison Laboratory, Thomas A. Edison, Inc., West Orange, New Jersey.
[1] D. Shoenberg, Proc. Roy. Soc. (London) **A245**, 1–57 (1952).

E4. Eigenfunctions of S^2 by a Spin-Operator Method.* G. W. PRATT, JR.,† *M.I.T.*—A new spin-operator has been found which when operating on a single determinant of space-spin orbitals generates a state of definite multiplicity. This spin operator O commutes with S^2 and the Hamiltonian H of a many particle system. The operator O is Hermitian and $O^2=O$. By application of this operator in the proper manner, one can write down all of the linearly independent and orthogonal singlet states for an N electron problem. This spin-operator method of generating states of a definite multiplicity from a single determinant can be used to effectively reduce the labor involved in a configuration interaction treatment of an N electron system. The method is being applied to the configuration interaction treatment of the $Mn^{++}-O^{=}-Mn^{++}$ system which has previously been considered by Anderson in regard to superexchange and its relation to the theory of antiferromagnetism.

* Supported jointly by the Army, Navy, and Air Force.
† Staff member, Lincoln Laboratory, M.I.T.

E5. Phase Transitions in Antiferrolelectric $PbHfO_3$.* GEN SHIRANE† AND RAY PEPINSKY, *The Pennsylvania State College.*—Phase transitions in ceramic $PbHfO_3$ have been studied by dielectric and structural measurements. The dielectric constant *vs* temperature curve shows two anomalies, at 160°C and 210°C. Between −170°C and 300°C the $P-E$ relation is almost linear, showing no ferroelectric hysteresis loops. At room temperature $PbHfO_3$ has a tetragonal lattice of perovskite type with $a=4.136$A and $c/a=0.991$, and a powder photograph shows some superstructure lines which have essentially the same character as those of $PbZrO_3$. This shows that $PbHfO_3$ is an antiferroelectric of the $PbZrO_3$ type below 160°C. The crystal structure between 160°C and 210°C has turned out to be also a tetragonal lattice as is the lowest phase, but the axial ratio c/a is much nearer to unity, 0.997, and the observed superstructure lines are different from those of the lowest phase. This indicates that the intermediate phase is another antiferroelectric phase which has a different type of dipole arrangement from that of the lowest phase. At 210°C, it becomes paraelectric, accompanied by a structural change to a cubic lattice.

* Development supported by Wright Air Development Center and U. S. Office of Naval Research Acoustics Branch.
† On leave from Tokyo Institute of Technology, Tokyo, Japan.

E6. A Phase Transition in CsH_2AsO_4.* B. C. FRAZER, *Brookhaven National Laboratory,* AND RAY PEPINSKY, *Pennsylvania State College.*—Ferroelectricity has been reported for all of the tetragonal dihydrogen phosphates and arsenates of K, Rb, and Cs except for CsH_2AsO_4. A Curie point of 143°K has been found for this crystal by dielectric constant measurements on a capacity bridge. Typical ferroelectric hysteresis loops were observed below the transition temperature. This study was undertaken primarily for the purpose of completing the series so that ferroelectric properties of its members could be viewed from the standpoint of their crystal chemistry. One

finds that the larger the alkali cations are, relative to the size of the XO_4 groups, the higher the Curie points. While complete data are lacking, the dielectric constants seem to vary also in a more or less predictable way: the larger the alkali cations relative to the XO_4 groups, the smaller the dielectric constants. These observations bear an interesting relation to the x-ray analysis of the KH_2PO_4 transition, in which the largest ionic displacement occurred in the case of K. As with their dielectric properties, the ammonium salts are exceptions: increasing the relative size of the NH_4^+ ion, by replacing As by P, decreases the transition temperature. This may prove to be of some significance in relation to the presumed antiferroelectricity of these salts.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

E7. Threshold Field and Free Energy for the Antiferroelectric-Ferroelectric Phase Transition in Lead Zirconate. A. DEBRETTEVILLE, JR., *Squier Signal Laboratory.*—Sawaguchi and Kittaka[1] obtained the threshold field of $PbZrO_3$—that necessary to change the antiferroelectric to the ferroelectric phase, below the Curie temperature. The free energy difference between the two phases is obtained by integrating the area between the dielectric displacement (ordinate) and the field strength (abscissa) or the hysteresis loop in the ferroelectric phase. An expression for free energy has been obtained as a function of voltage, by eliminating the temperature parameter. This experimental relationship is compared with the author's theoretical expression—one that involves the product of twice the constant spontaneous polarization[2] (6 microcoulombs/cm² in the ferroelectric phase), the threshold voltage, and the molar volume (42 cm³); the free energy so calculated is small—of the order of 3 calories/mole at 25 kv/cm. The agreement between experimental and theoretical values is good. Equations are also given for calculating the threshold field strength and free energy difference as functions of temperature. The equation for threshold field strength resembles the Clapeyron-Clausius equation, with field strength analogous to pressure and spontaneous polarization analogous to volume.

[1] E. Sawguchi and T. Kittaka, J. Phys. Soc. Japan **7**, 336–337 (1952).
[2] Shirane, Sawguchi, and Takagi, Phys. Rev. **84**, 476–481 (1951).

THURSDAY AFTERNOON AT 2:00

Page Auditorium

(JOHN BARDEEN presiding)

Division of Solid-State Physics

Symposium on Semiconductors

F1. Transistor Experiments on Binary Lead Compounds. H. K. HENISCH, *University of Reading.* (30 min.)

F2. Electrons and Holes in Electric and Magnetic Fields. WILLIAM SHOCKLEY, *Bell Telephone Laboratories.* (30 min.)

F3. Infrared Absorption in Elementary Semiconductors, H. Y. FAN, *Purdue University.* (30 min.)

F4. Infrared Absorption and Photoconductivity in Tellurium. P. H. MILLER, *University of Pennsylvania.* (30 min.)

F5. Optical and Photoconductive Investigations of Impurity Levels in Germanium and Silicon. E. BURSTEIN, *Naval Research Laboratory.* (30 min.)

THURSDAY AFTERNOON AT 2:00

Chemistry 116

(OTTO STUHLMANN presiding)

General Physics

G1. Effect of a Centrifugal Force Field on the Response of a Vibrating Mass-Spring System. W. A. WILDHACK AND R. O. SMITH, *National Bureau of Standards.*—The earth's gravitational field furnishes a convenient sinusoidal forcing function for a vibrating system (e.g., an accelerometer) rotating in a vertical plane. The centrifugal field decreases the restoring force on the vibrating mass. Resonance occurs at lower frequencies and with greater amplitudes than in the case of excitation by linear vibration. The response ratio (vibration amplitude/static displacement caused by gravity) is greater than unity for all damping ratios up to unity. The resonant frequency for zero damping occurs at 0.707 times the natural undamped frequency. From measurements of the maximum response ratio, and of the frequency at which this ratio decreases to unity, one may determine both the damping ratio and the undamped natural frequency of any system whose damping ratio is less than unity. The response to the centrifugal field is infinite at a rate of rotation equal to the natural undamped frequency, although the response to the sinusoidal field decreases asymptotically towards zero at higher rotational frequencies.

G2. The Motion of Ions in Perpendicular HF Electric Fields. M. S. MCCAY AND J. H. COULLIETTE, *University of Chattanooga.*—Ion motion studies, usually limited to the cases of (a) magnetic, (b) electric, and (c) electric and magnetic

fields at arbitrary angles, have been extended to the case of (d) oscillating electric fields at right angles. With the ion injection axis perpendicular to the crossed electric fields, which are operated under circular-sweep phase conditions, excellent isotopic separation is indicated, with defocusing interaction between adjacent beams reduced to a minimum by the rotary-sweep motion.

G3. A Study with a NaI Scintillation Spectrometer of Methods of Estimating I^{131} Contained in the Human Thyroid. ROBERT J. KERR, SHERWOOD K. HAYNES, AND GEORGE R. MENEELY, *Thayer Veterans Administration Hospital and Vanderbilt University.*—External gamma-counting of I^{131} in the human thyroid, widely used in medical diagnosis, is subject to errors due to scattered radiation. A NaI(Tl) scintillation spectrometer was used to investigate the spectrum of I^{131} in the thyroids of two patients to evaluate methods of correcting these errors. Spectra were also taken of a point source, a 100 ml volumetric "duplicate" source and a phantom made by immersing this flask in a two-liter beaker of water. These measurements were also made through a ½-in. Pb filter. Differences in each of these spectra were observed and will be presented. Computed integral spectra show that either a bare duplicate or a bare phantom may yield errors of ±7 percent for the best discriminator setting (~250 kev) and much larger errors for lower discriminator settings. A ½-in. Pb filter gave consistent values for the two patients independent of discriminator setting, although in each case the estimated content was 6 to 10 percent low. These inconsistencies would be exaggerated by Geiger counters which are most sensitive at low energies. Therefore, of the methods tested, accurate measurements can only be made with a properly designed phantom and a Pb filter.

G4. Spectrographic Analysis of Human Tissue. ISABEL H. TIPTON, W. D. FOLAND, FRANKLIN C. BOBB, AND W. C. MCCORKLE, *The University of Tennessee.*—Over 200 specimens of normal human tissue from 42 individuals from Boston, Massachusetts; Columbus, Ohio; Memphis, Tennessee; and Birmingham, Alabama have been analyzed semiquantitatively for 23 elements. The tissue spectra were compared visually with the spectra of 10 standards of synthetic tissue ash composed of a matrix of potassium di-hydrogen phosphate, sodium chloride, magnesium oxide, calcium carbonate, and iron oxide with twenty-three elements added in concentrations of 1000, 400, 200, 100, 40, 20, 10, 4, 2, and 1 ppm. Certain elements such as manganese and copper were found in nearly the same concentration in all samples of a certain tissue whereas others, such as boron, chromium, and nickel occurred in widely varying concentrations. The most startling discovery was the appearance of more than 1000 ppm of cadmium in every kidney specimen.

G5. Biophysical Study of Burns. IRWIN GRAHAM, DAVID POMEROY, W. C. MCGARVEY, AND JOHN G. RANDALL.—Rats were irradiated so as to produce local burns of varying severity. The gross appearance of the different stages leading to lesions with the subsequent healing process was correlated with histological analysis. The physical irradiation conditions were varied so as to investigate the influence of wavelength and spectral energy composition changes on the topical reactions. These experiments extended earlier work performed in this lab.[1] In conformity with the pioneering ideas of Selye[2] for a unified theory of medicine, burn studies were made also on adrenalectomized and hypophysectomized rats. Results indicated that vesicles form with greatest difficulty in the case of the adrenalectomized rats and that the healing time is also least for those rats. Rats which have had their pituitary glands removed develop vesicles with the same readiness as intact rats, but the degree of edema appears to be less, and the resorption is easier. Duplication of the course of the burns was obtained with varying success by administration of specially selected substances.

[1] K. Schocken et al., October, 1952 (unpublished).
[2] Hans Sleye, *Stress, a Treatise Based on the Concept of the General-Adaptation-Syndrome and the Diseases of Adaptation* (Acta Inc., Medical Publishers, Montreal, Canada, 1950).

G6. A Report on the Measurement of the Thickness of Thin Films by Employing Electron Microscope Shadowcasting Technique. GEORGE W. CRAWFORD, *Clemson Agricultural College* (introduced by L. D. Huff).—In studying the properties of thin films (thicknesses less than 500A) using the electron microscope, it became necessary to find a method of accurately determining the thickness of very thin films. Such a method was found by applying electron microscope shadowcasting technique to the problem. When the film is first prepared by evaporation, care is taken to obtain an edge whose top is level with the rest of the film and which has a vertical cliff. This edge is then shadowcast and a picture of the edge of the cliff and its shadow is taken using the electron microscope. The length of the shadow on the negative is then measured using a traveling microscope and knowing both the angle at which the shadow was cast and the magnification factor for that negative, the thickness of the film is calculated.

G7. Polarization in Liquids of Intermediate Conductivity.* JOHN A. RIDER, *Louisiana State University* (introduced by Lloyd W. Morris).—This investigation was undertaken in order to test the application of the Jaffé theory of conductance in polarizable media[1] to liquids having a range of conductance which has received little attention from the standpoint of polarization. This is the range between electrolytic solutions of conductance $K < 10^{-6}$ ohm^{-1} cm^{-1} and dielectric liquids of conductance $K > 10^{-17}$ ohm-cm^{-1}.[2,3] Measurements have been made on hexane, isopropyl ether, and dibromobenzene in varying degrees of purity.

* Work supported in part by U. S. Office of Naval Research.
[1] G. Jaffé, Ann. phys. **16**, 217, 249 (1933).
[2] G. Jaffé and J. A. Rider, J. Chem. Phys. **20**, 1077-1087 (1952). This paper contains a complete listing of earlier electrolytic work.
[3] G. Jaffé and C. LeMay, J. Chem. Phys. (to be published). This paper will contain a listing of earlier dielectric work.

G8. A General Method for Predicting the Molar Activity Coefficients of Electrolytes from Conductivity Data.* HENRY P. MARSHALL AND ERNEST GRUNWALD, *Florida State University.*—We have obtained an expression for the molar activity coefficients of uni-univalent electrolytes which applies whenever the electrolyte exists partly as free ions and partly as short-range ion pairs. The derivation is based on the approach of Bjerrum and postulates the existence of a quasi-equilibrium between the free ions and the ion pairs. The interionic free energy of the free ions is calculated by applying the methods of Debye and Hückel to our model. The quasi-equilibrium constant for the ion pair dissociation is obtained from conductivity data by a method similar to that of Fuoss and Kraus but consistent with our model. The equations are tested by means of the data for hydrochloric acid in solvents ranging in dielectric constant from 40 to 10. In this range, the quasi-dissociation constant of the ion pairs is the only constant contained in our equations which is characteristic of the electrolyte. The conductivity data therefore uniquely prescribe the molar activity coefficients, and our predicted values agree well within 2 percent with those determined from emf measurements up to electrolyte concentrations of the order of 0.01M.

* This work was done in collaboration with the Office of Ordnance Research.

G9. Electric Conduction at Metal-Semiconductor and Metal-Solution Interfaces. HUNG-CHI CHANG, *Louisiana State University* (introduced by Lloyd W. Morris).—The

generalized Jaffé theory of polarization for electrolytic solutions, dielectric liquids and semiconductors[1] is further extended so as to include an intermediate layer of high insulation between the metal and the polarization layer. This thin layer may be either the Helmholtz monolayer, or one formed electrochemically. Its thickness is treated as current dependent and is therefore a function of the applied potential, frequency, and concentration. The calculation of the equivalent parallel resistance and capacitance has been carried to the second order of approximation. The introduction of this intermediate layer affords an explanation of the increase in capacitance observed at low frequencies, as well as the long time required for the chanrging current to reach steady state in dielectric liquids. These phenomena have been explained by the Jaffé theory on the basis of slow ions. The present theory provides an alternative interpretation of these phenomena. In addition the inductive character of the action at the interface observed under some conditions of bias can be predicted qualitatively

[1] Hung-Chi Chang and George Jaffé, J. Chem. Phys. **20**, 1071 (1952).

G10. A Continuous Flow Cell for the Investigation of Polarization at Metal-Solution Interface. L. W. Morris and Hung-Chi Chang, *Louisiana State University.*—It is well known that the reproducibility of measurements on electrolytic polarization is rather poor, since the polarization effects depend strongly on surface conditions which are difficult to control, especially when chemical reactions occur at the electrode surface. A continuous flow cell has been developed, which consists of a pair of demountable electrodes with a fixed separation of 0.318 cm and an effective area of 7.92 cm². The solution moves steadily past the electrodes isolated from contact with the unfiltered atmosphere. To give an instance of the reproducibility obtained for one specimen of water, at frequency of 1000 cps, the resistance was measured as 24 720 ohms and the capacitance as 0.172 mfd. At a time 28.5 hours later the measurements yielded 24 710 ohms and 0.171 mfd. This continuous flow cell has been used for studying electrolytic rectification with aluminum as electrodes and ammonium borate as electrolytes. The series capacitance and resistance of this cell were measured over a range of frequencies from 18 cps to 18 kcps. Measurements were made at 0.0001, 0.001, and 0.01 *M* concentrations and after forming at voltages of 22.5, 45, 90, 135, and 180 v. The results are discussed according to the generalized Jaffé theory described in Paper No. G9.

G11. The Solubility of Solids in Gases. A. H. Ewald (introduced by W. G. Schneider).—In a system consisting of a pure solid in equilibrium with a nonreacting compressed gas, the mole-concentration x_2 of the solid component in the gas phase can be expressed by[1]

$$\ln\frac{x_2}{x_2^0}=\frac{V\text{solid}P}{RT}-\frac{2B_{12}}{V_m}-\frac{3}{2}\frac{C_{112}}{V_m^2}-\frac{4}{3}\frac{D_{1112}}{V_m^3},$$

where x_2^0 is the concentration corresponding to the normal vapor pressure of the solid. The first term represents the Poynting pressure effect while the remaining terms represent the interactions of single solute molecules with gas molecules. The mixed virial coefficient B_{12} may be calculated from the properties of the pure components by the principle of corresponding states, while this method leads to only a first approximation for the higher coefficients. Values calculated by the equation are in fair agreement with experiments. Solubilities measured at moderate pressures may be used to determine B_{12}. A radioactive tracer method has been used to measure the solubility of *p*-chloroiodobenzene in compressed ethylene.[2]

[1] Ewald, Jepson, and Rowlinson, "Equilibrium properties of non-electrolytes and non-electrolyte solutions," Faraday Soc. Disc. (to be published).
[2] A. H. Ewald, Ph.D. thesis, Manchester, 1952 (to be published).

Thursday Afternoon at 2:00

Biology 113

(Fritz London presiding)

Cryogenics

GA1. Atomic Heat of Germanium below 4°K. P. H. Keesom and N. Pearlman, *Purdue University.*—The Debye θ of pure Ge has been reported as 278°K, from measurements below 4°K of the atomic heat of crushed Ge in a Cu calorimeter.[1] We found, however, 369°K for Ge in the form of ingots.[2] We have now also measured the atomic heat of pure crushed Ge. Above 3°K the results agree with the previous ingot measurements. Below this temperature, there is a small additional heat capacity which decreases when the amount of He exchange gas in the calorimeter is reduced. This can be accounted for by desorption of exchange gas from the small Ge particles (0.1–3 mm). We conclude from measurements on seven ingots of various sizes and shapes and the crushed sample that below 3°K (the upper limit of the true T^3 region) θ is (364±3)°K, in agreement with Parkinson's estimate from atomic heat data[3] and the value, 375°K, which we calculate from elastic constants.[4]

[1] I. Estermann and S. A. Friedberg, Phys. Rev. **85**, 715 (1952).
[2] P. H. Keesom and N. Pearlman, Phys. Rev. **85**, 730 (1952).
[3] R. W. Hill and D. H. Parkinson, Phil. Mag. **43**, 309 (1952).
[4] Bond, Mason, McSkimin, Olsen, and Teal, Phys. Rev. **78**, 176 (1950).

GA2. Low Temperature "Breakdown" Effect in Germanium. N. Sclar, E. Burstein, W. J. Turner, and J. W. Davisson, *Naval Research Laboratory.*—Current-voltage measurements on germanium at liquid helium temperatures using dc and microsecond pulses have revealed the existence of a reversible, nondestructive, "breakdown" effect for low applied voltages. The "breakdown," which manifests itself as a sharp increase in current of several orders of magnitude over a small range in voltage, takes place in both "*n*" and "*p*" type germanium. Exposure of the specimen to room temperature background radiation increases the current in the pre-breakdown region but does not effect the current at higher voltages. The effects of room temperature radiation, which are due to the photoionization of neutral impurities, imply that the charge carrier density in the breakdown region is markedly greater than in the pre-breakdown region. It is suggested that the "breakdown" effect is the result of charge carrier multiplication by impact ionization of neutral impurities in which the free charge carriers gain the necessary energy from the applied field. The relatively low voltage required for "breakdown" is accordingly attributed to the high mobility of the charge carriers in germanium at low temperatures.

GA3. Method for Measuring Magnetic Moments of Superconductors. Ted G. Berlincourt and M. C. Steele, *Naval Research Laboratory.*—A torsion balance has been used to measure the couple acting on a small tin cylinder placed in a

homogeneous magnetic field with its axis making an angle of approximately 30° with the field. The method, which is also applicable for very nearly transverse or longitudinal fields, differs from that used by Alekseyevsky[1] in that very small deflections are utilized so that the specimen orientation is not appreciably altered even at maximum moment. The observed magnetization curves are strictly linear in the superconducting region. In some cases a discontinuity was observed as the specimen entered the intermediate state, which is qualitatively in accord with current theories of the intermediate state.[2,3] The method should be applicable to magnetic moment measurements on superconductors in the adiabatic demagnetization temperature range.

[1] N. E. Alekseyevsky, J. Phys. (U.S.S.R.) **4**, 401 (1941).
[2] L. D. Landau, J. Phys. (U.S.S.R.) **7**, 99 (1943).
[3] C. G. Kuper, Phil. Mag. **42**, 961 (1951).

GA4. Adiabatic Magnetization of a Superconducting Sphere. R. L. DOLECEK, *Naval Research Laboratory.*—Temperature changes accompanying suppression of the superconductivity of a lead sphere by adiabatic magnetization have been investigated. Measurements were taken of the cooling produced by adiabatic magnetization and the heating produced by adiabatic demagnetization. The magnetic fields were applied and removed as step functions of time and allowance was made for the resulting eddy current heating. Observations were made in the temperature range 2.2°K to 5.0°K for fields in the range. $1.18>h>0.77$ where h is the ratio of applied field to critical magnetic field. This range of magnetic fields corresponds to $0.3<x\leq 1.0$ where x is the fraction of the lead sphere that becomes normal when the sphere is subjected to a magnetic field sufficient to produce the intermediate state, *viz.*, $\frac{2}{3}<h<1.0$. Temperature changes observed on magnetization and demagnetization are in quantitative agreement with values predicted from calorimetric data and thus confirm the gross aspects of current interpretation of the entropy of a superconductor in the intermediate state.

GA5. Search for the Hall Effect in a Superconductor. H. W. LEWIS, *Bell Telephone Laboratories.*—Since the first experiments of Kamerlingh Onnes and Hof, in 1914, it has been widely believed that there is no Hall effect in the superconducting state. However, these first experiments were performed on samples that must have been, in fact, in the intermediate state (which was not, of course, known at the time) so that the experimental question must be considered still open. A search has been made, by a new method, on a specimen of superconducting vanadium, and the preliminary result is negative, with an upper limit of about twenty to thirty percent of the normal expected Hall coefficient. The theoretical implications will be discussed.

GA6. Theory of Pressure Effects on Superconducting Transition Temperatures. PAUL M. MARCUS, *Carnegie Institute of Technology.*—Measurements[1] of effects of hydrostatic pressure, p, on superconducting transition temperatures, T_c, show in general a decrease of T_c. The magnitude of the effect is understandable by a treatment like that given the isotope shift by the lattice vibration interaction theory[2] and constitutes another test of that theory. In both cases the single electron interaction energy, Δ, is assumed proportional to the mean-square lattice vibration amplitude, $(q^2)_{Av}$, in the zero-point oscillation. For isotopes $(q^2)_{Av}$ decreases as lattice mass increases; here it decreases because the force constant increases as the lattice is compressed. Change of force constant or, equivalently, of frequency with lattice size is estimated from Gruneisen's constant γ. Since Δ is proportional to kT_c, as follows easily from a model of the second-order transition, such as the two fluid model, we obtain $(d\ln T_c/dp) = -V\alpha/C_V$ with volume expansivity α, molar volume V, molar heat capacity C_V. This gives for indium, the best case, $dT_c/dp = -2.1\times10^{-11}$ °K dyne^{-1} cm^2 *vs* measured value -4.7×10^{-11}.

[1] Kan, Sudovstov, and Lasarew, J. Exptl. Theoret. Phys. U.S.S.R. **18**, 825 (1948).
[2] J. Bardeen, Phys. Rev. **80**, 567 (1950).

GA7. The Superconducting Transition in Aluminum.* D. E. MAPOTHER AND J. F. COCHRAN, *University of Illinois.*—The superconducting transition in aluminum has been studied down to about 0.75°K using a cryostat in which the cooling is produced by pumping over liquid helium. Measurements are made at constant temperature in a dc magnetic field whose value is changed in a stepwise manner by increments of the order of a few tenths of an oersted. The resulting changes in the flux through the sample are detected by a ballistic induction method. Measurements have been made on a single crystal sample of aluminum (purity 99.997 percent) which was cast in an accurate ellipsoidal shape. The transitions observed are quite sharp being of the order of 0.5 oersted when going from the superconducting to the normal state. The transition from the normal to the superconducting state occurs with complete abruptness since the supercooling characteristic of aluminum[1] is very pronounced. The ratio of the field for the supercooled transition to the critical field is about 0.60 at the lowest temperatures measured and decreases with increasing temperature. The Meissner effect for this sample appears to be better than 97 percent complete.

* Supported in part by the U. S. Office of Ordnance Research and the U. S. Office of Naval Research.
[1] D. Shoenberg, Proc. Cambridge Phil. Soc. **36**, 84 (1940).

GA8. Helium II: Bose-Einstein Condensation and Two-Fluid Model. P. R. ZILSEL, *University of Connecticut.**—Imposing a total momentum on a Boltzmann or Fermi-Dirac gas shifts the equilibrium distribution as a whole in momentum space, but does not change its character. However, for some forms of the energy spectrum in the case of a degenerate Bose gas, the condensed state does not participate in the imposed motion, and a relative velocity $\mathbf{v}$ results between the condensed state and the center of mass of the excited states. The total momentum is $\mathbf{P}=M_n\mathbf{v}$ (M_n=effective mass of the excited part). For the energy E' in the rest system of the condensate one then has $dE'=TdS-PdV+\mathbf{v}\cdot d(M_n\mathbf{v})$, which leads to the same two-fluid equations of motion derived previously from a variational principle.[1] The "rigidity" of the condensate in momentum space plays the same role as the rigidity of the superconducting electrons on imposition of a magnetic field in the London theory. The state of relative motion between the condensate and the excited particles is macroscopically metastable.

* Assisted by a Research Corporation grant.
[1] P. R. Zilsel, Phys. Rev. **79**, 309 (1950).

GA9. An Apparatus for Magnetic Measurements at Low Temperatures. R. A. ERICKSON, *University of Tennessee,* AND L. D. ROBERTS, *Oak Ridge National Laboratory.*—A cryostat and Hawtshorn type mutual inductance bridge have been built for the measurement of the magnetic properties of antiferromagnetic and paramagnetic compounds continuously over the temperature region from 80°K down to the temperatures obtained by magnetic cooling (~0.01°K). This apparatus is an improvement on previous designs in that a somewhat higher usable sensitivity (2×10^{-9} henry) has been obtained over a larger frequency range of approximately 0–10 kc. These improvements result from winding all coils in such a way as to reduce internal capacities; in connecting the variable mutual coils through reversing switches so that the calibration of the variable mutual inductance can be quickly and easily checked; and through the use of a twin T feed back amplifier in the CRO detection circuit which gives a Q of ~100 and a sensitivity of 10^{-8} volt. Data on manganous ammonium sulfate will be presented.

Post-Deadline Papers, if Any

THURSDAY AFTERNOON AT 2:00

Physics 114

(R. S. MARVIN presiding)

Division of High-Polymer Physics

Mechanical and Electrical Properties

GB1. Rheology of Polyisobutylene III. Approximation Methods in Linear Viscoelasticity Theory: Wiechert Function Calculations.* HERBERT LEADERMAN, *National Bureau of Standards.*—In connection with previously reported retarded elastic behavior of low molecular weight polyisobutylene,[1] a study has been made of the validity of approximation methods in the calculation of the retardation time function $L(\ln\tau/\tau_0)$ and of dynamic response from creep data obtained from a Wiechert "model" retardation time function with $b=0.4$. First and second approximations for $L(\ln\tau/\tau_0)$ are calculated by the methods of Alfrey and Schwarzl.[2] Second approximations are also obtained by differentiating $J'(\omega\tau_0)$ calculated by Marvin's difference function[3] and by a new successive approximation method. Alfrey's and Schwarzl's approximations were obtained also by fitting retarded elasticity data (from the "model" function) to a Kohlrausch type function. Marvin's difference function method appears to be the best way of computing $J'(\omega\tau_0)$ from creep data. $J''(\omega\tau_0)$ has been computed from $J'(\omega\tau_0)$ (a) by an approximate method using a difference function and (b) exactly by a Kronig-Kramers integral.

* Supported by the U. S. Office of Naval Research and Office of the Quartermaster General.
[1] H. Leaderman and R. G. Smith, Phys. Rev. **81**, 303 (1951).
[2] F. Schwarzl and A. J. Staverman, Physica **18**, 791 (1952).
[3] R. S. Marvin, Phys. Rev. **86**, 644 (1952).

GB2. Dynamic Mechanical Properties of Polyisobutylene. EDWIN R. FITZGERALD,* LESTER D. GRANDINE, JR.,† AND JOHN D. FERRY, *University of Wisconsin.*—Values of complex shear compliance (and rigidity) have been obtained for a sample of polyisobutylene of viscosity-average molecular weight 1.35×10^6, distributed by the National Bureau of Standards, at 22 temperatures from -45 to 100°C and at about 20 frequencies from 30 to 5000 cps. Measurements were made by means of the transducer method of Fitzgerald and Ferry with a precision of ±2 percent and are estimated to be accurate to within ±3 percent as evidenced by agreement obtained between 7 different samples of widely varying dimensions. Values of the real part of the complex shear compliance, J', vary from 3.1×10^{-7} cm²/dyne at 99.9°C to 1.0×10^{-10} cm²/dyne at -44.6°C. The frequency dependence of the loss tangent J''/J' indicates the presence of a low, broad maximum of 1.7 at -10 to -5°C and a second, smaller maximum or plateau at lower temperatures. This second maximum is also evident in a plot of J''/J' at a fixed frequency against temperature. The wide temperature and frequency ranges of the measurements have provided an essentially complete experimental description of the dispersion region in polyisobutylene corresponding to the transition from a rubber-like elasticity to that of a hard glass.

* Present address: Pennsylvania State College.
† Present address: E. I. du Pont de Nemours and Company.

GB3. The Relaxation Distribution Function of Polyisobutylene in the Transition from Rubberlike to Glasslike Behavior and its Dependence on Temperature. JOHN D. FERRY, LESTER D. GRANDINE, JR.,* AND EDWIN R. FITZGERALD,† *University of Wisconsin.*—The steady flow viscosity of a sample of polyisobutylene of viscosity-average molecular weight 1.35×10^6 (distributed by the the National Bureau of Standards) has been measured from 15° to 97°C; its logarithm is a linear function of $1/T$. The complex compliance of this material, $J'-iJ''$, as reported previously from -45° to 100° and from 30 to 5000 cps, has been analyzed by the method of reduced variables modified[1] to account for the glasslike compliance; it yields single composite curves for J' and J''. The values of a_T, the temperature reduction factor, are slightly but significantly larger than those derived directly from the viscosity; the latter, however, agree with those derived from stress relaxation measurements of Tobolsky and McLoughlin.[2] The reduced loss tangent, J_p''/J_p', as a function of reduced frequency is broader than in other polymers and shows the secondary plateau apparent in the original data. The distribution functions of relaxation and retardation times are similar in shape to those of other polymers in the transition from rubberlike to glasslike behavior.

* Present address: E. I. du Pont de Nemours and Company.
† Present address: Pennsylvania State College.
[1] Fitzgerald and Ferry, J. Colloid Sci. (to be published).
[2] Tobolsky and McLoughlin, J. Polymer Sci. **8**, 543 (1952).

GB4. Dynamic Properties of Unvulcanized GR-S.* L. J. ZAPAS, S. L. SHUFLER, AND T. W. DEWITT, *Mellon Institute* (introduced by R. S. Marvin).—Dynamic moduli and loss factors have been measured on a sample of unvulcanized GR-S at temperatures between -68°C and $+63$°C. The frequencies employed ranged from about 5×10^{-4} cps to 3 cps. This range of frequencies and temperatures was sufficient to include nearly the whole of the glassy transition region where the shear modulus drops abruptly from about 1×10^{10} dynes/cm² to about 1×10^7 dynes/cm² where there is a suggestion of a plateau. At higher temperatures, the modulus drops off gradually and continuously, presumably to zero. The lowest measured value was about 3×10^5 dynes/cm². When plotted in terms of reduced variables, the data cover a considerable section of the useful mechanical frequency spectrum for this sample of GR-S. The data are compared with stress relaxation measurements reported in the literature.

* This work was supported by the Office of Synthetic Rubber, Reconstruction Finance Corporation.

GB5. Dynamic Properties of Concentrated Polymer Solutions.* F. J. PADDEN, H. MARKOVITZ, AND T. W. DEWITT, *Mellon Institute.*—The dynamic rigidities and viscosities of a variety of solutions of polyisobutylene in decalin have been determined in the neighborhood of room temperature and at frequencies between 10 and 100 cycles per second. Zero shear viscosities of these solutions have been measured by both falling ball and capillary methods. Concentration and molecular weight of the solute were the main variables and ranged from a 5 percent solution of a sample of molecular weight 2.5×10^6 to a 40 percent solution of a sample of molecular weight 1.5×10^5. When reduced variables that take into account concentration and temperature are used, superposition of data from samples of different molecular weights is not achieved. A scale shift that is equivalent to treating molecular weight semiquantitatively as an inverse concentration achieves reasonable superposition and suggests that the important variable is the number of chains per unit volume. The

results are compared with some previously obtained on low molecular weight oils and on whole polymer.

* This work was supported by the Office of Synthetic Rubber, Reconstruction Finance Corporation.

GB6. Calculation of Extrusion Behavior of Viscoelastic Materials from the Relaxation Distribution Function. THOR L. SMITH, *Hercules Powder Company* (introduced by R. S. Marvin).—A viscoelastic material when extruded rapidly through a short capillary or spinneret may exhibit an effective viscosity which is smaller by a factor of several hundred than the viscosity as usually measured at low shear rates. An equation is derived which expresses the effective viscosity as a function of the time the material spends in the spinneret (transit time) and the distribution function of Maxwellian relaxation times. In the derivation it is assumed that the mechanical properties of the material may be represented by a generalized Maxwell model. Effective viscosities observed when a 25 percent cellulose acetate solution is extruded through a spinneret with radius 0.006 cm and effective length 0.0186 cm are given. The relaxation distribution function for the solution is calculated from the published dynamic viscosity data of Philippoff. From the distribution function and values of the transit time, effective viscosities are calculated and found to agree with the experimental values to within factors of 1.2 to 3.1. This agreement is considered satisfactory in view of the fact that all nonlinear effects (non-Newtonian and non-Hookean) are neglected in the calculations and the effective viscosities are smaller than the usual flow viscosity by factors of 150 to 10.

GB7. Dielectric Relaxation in a Styrene-Acrylonitrile Copolymer during and after its Polymerization.* P. EHRLICH AND N. J. DELOLLIS, *National Bureau of Standards* (introduced by P. J. Franklin).—Dielectric relaxation in a plasticized copolymer of styrene and acrylonitrile during its polymerization and in the fully polymerized resin is studied by means of measurements of dielectric constant and loss tangent at frequencies from 10^2 to 10^5 cps. Drastic changes in dielectric constant and loss occur during the polymerization. These are interpreted as resulting from the relaxation of the nitrile groups at a rate which depends strongly on the extent of the polymerization. There is a striking parallelism between the electrical properties of the fully polymerized copolymer as observed at elevated temperatures and those of the partly polymerized reaction system at an early stage of the reaction and at a lower temperature: values of the loss factor are similar at equal average relaxation times and in each case there is a similar broadening of the relaxation distribution function as cross links are introduced. Values of the heats and entropies of activation are consistent with the picture of dipole relaxation.

* Supported by Chief of Ordnance.

GB8. Dielectric Dispersion of Polar Polymers at Microwave Frequencies. T. M. SHAW AND J. J. WINDLE, *Western Regional Research Laboratory.*—The dielectric properties of wool and mohair have been investigated at frequencies of 3000 Mc and 10 000 Mc by means of a cavity resonator method. The resonator previously described[1] was provided with a slot parallel to the direction of current flow in the cavity, which allows the use of taut fiber specimens. Fibers are mounted on a frame which, when inserted in the slot in the cavity, positions the fibers precisely on the cavity axis. It was found that the dielectric constant, ϵ, at 25°C, of oven-dry wool is the same, within experimental error, as that of oven-dry mohair. For wool $\epsilon = 3.70 \pm 0.04$ at 3000 Mc and 3.54 ± 0.04 at 10 000 Mc. These values are significantly smaller than the value $\epsilon = 4.2 \pm 2$ percent reported by Errera and Sack[2] for lower frequencies and are large compared to the square of the index of refraction for visible light, $n^2 \sim 2.4$. In a survey of the dielectric properties of other hydrogen-bonded polymers, large differences between the dielectric constant for frequencies in the microwave range and n^2 were also found.

[1] T. M. Shaw and J. J. Windle, J. Appl. Phys. **21**, 956 (1950).
[2] J. Errera and H. S. Sack, Ind. Eng. Chem. **35**, 712 (1943).

Invited Paper

GB9. Relaxation Distribution Functions of Polymers and Their Concentrated Solutions and Gels. J. D. FERRY, *University of Wisconsin.* (30 min.)

FRIDAY MORNING AT 10:00

Page Auditorium

(HARVEY BROOKS presiding)

Division of Solid-State Physics

Color Centers

Invited Paper

H1. Current Status of the F-Center Problem in Alkali Halides. F. SEITZ, *University of Illinois.* (50 min.)

H2. *Z*-Centers in Alkali Halides.* D. R. WESTERVELT, *North American Aviation, Inc.*—The secondary absorption band resulting from heat treatment of crystals containing *F*-centers differs in several respects from the well-known bands produced by *F*-light bleaching. This band, which has been isolated in additively colored crystals by Scott and Smith,[1] and in electron bombarded crystals by the writer,[2] is produced also in crystals heavily darkened by x-rays; hence it is not peculiar to any coloring method. The earliest systematic study of the effects of thermal annealing on heavily colored crystals appears to be due to Przibram[3] and his coworkers, and it is suggested that their appropriate term *Zwischenzentren* be adopted to designate the absorption centers resulting from heat treatment. The room temperature

absorption peak of the Z-band lies at 580, 765, and 825 mμ in NaCl, KCl, and KBr, respectively. It is independent, in additively colored crystals, of the metal added. The location, height, and width of the Z-band are relatively, but not completely, insensitive to temperature, in contrast to these properties of the F, M, R, N, and K-bands, which are strongly affected. The growth rate of the R-bands during F-light irradiation is independent of the presence of Z-centers.

* This report is based on studies conducted for the U. S. Atomic Energy Commission under contract AT-11-1-GEN-8.
[1] A. B. Scott and W. A. Smith, Phys. Rev. **83**, 982 (1951).
[2] D. R. Westervelt, Phys. Rev. **86**, 643 (1952), Bull. Am. Phys. Soc. **27**, 9 (1952).
[3] K. Przibram, Z. Physik **130**, 269 (1951), summarizes much of this work.

H3. Bleaching Properties of *F*-Centers in KBr at 5°K.* J. J. MARKHAM, R. T. PLATT, JR., AND I. L. MADOR, *The Johns Hopkins University.*—The bleaching properties of F-centers in KBr have been investigated experimentally at 5°K and 78°K. A Beckman spectrophotometer was used for measuring the absorption spectra and for bleaching the crystals. The stability of F-centers towards bleaching at 5°K and at 78°K is dependent on the mode of formation. Those produced by additive coloration are stable; those produced at room temperature by x-rays bleach slightly; those produced at 78°K by x-radiation show some bleaching; while those produced at 5°K by x-radiation show a large initial instability. The properties of F-centers made by a pointed cathode by excitons or by electron bombardment have not been explored. Some tentative theoretical conclusions will be made.

* This research was supported by the U. S. Navy Bureau of Ordnance.

H4. The Band Width of *F*-Centers in KBr.* I. L. MADOR, J. J. MARKHAM, AND R. I. PLATT, JR., *The Johns Hopkins University.*—The absorption spectra of color centers in alkali halides may be characterized by the wavelength of maximum absorption and the half-width (difference between the wavelengths where the absorption is half the maximum value.) Previous measurements[1,2] indicate that the half-width may not be a unique property of a crystal, but may vary from sample to sample. The comparison of data from various experimenters is not valid because of uncertainty in spectral slit widths employed. A series of measurements have been made on F-centers in KBr at 5°K and at 78°K. The centers were formed by x-radiation at various temperatures and by additive coloration with excess potassium. The data on half-widths and wavelength maxima will be presented.

* This research was supported by the U. S. Navy Bureau of Ordnance.
[1] A. Smakula, Z. Physik **59**, 603 (1930).
[2] W. H. Duerig and J. J. Markham, Phys. Rev. **88**, 1043 (1952).

H5. Production of *F'*-, *M*-, and *R*-Centers in NaCl at Room Temperature.* R. T. PLATT, JR., I. L. MADOR, AND J. J. MARKHAM, *The Johns Hopkins University.*—One may produce a variety of absorption centers to the long wavelength side of the F-band. The ones most carefully studied are the F'-, R_1-, R_2-, and M-bands. In NaCl at room temperature, the R-bands overlap and resemble the F'-band; indeed, it is not possible to tell if the "erregt" state, so extensively studied by the workers in Gottingen, is due to R- or F'-centers. An experimental study of these bands has been made. It indicates that during x-radiation the F-, F'-, and M-band form. Since the lifetime of the F'-band at 300°K is several minutes it dissociates during the course of the usual absorption measurement. To obtain reliable growth rate of the F-band during x-radiation the contribution of the F'-band must be taken into account. The R-bands are formed primarily by optical bleaching of the F-band. The experiments show that the "erregt" state at room temperature is due to the presence of the R-bands, not the F'-band. The coagulation of vacancies will be considered.

* This research was supported by the U. S. Navy Bureau of Ordnance.

H6. Electronic Structure of *F*-Centers. C. KITTEL, *University of California, Berkeley.*—Observations by Hutchison and Kip on the width of the microwave spin resonance absorption line associated with F-centers in KCl colored with excess K may be accounted for with the molecular orbital model of an F-center previously shown[1] to account for the g-value of the resonance. The observed line is Gaussian with width 57 oersteds, practically independent of concentration and quenching procedure. The theory of dipolar broadening[2] in randomly populated crystals leads to a Lorentzian line of width about 0.01 oersted. Interactions with nuclear spins on the usual central field model of an F-center gives ~1 oersted. The LCAO model[1] gives a width which may be calculated from the hyperfine interaction of the 4s state in the K atom. Taking the electron as shared among the six K^+ ions bounding the anion vacancy, there are 4096 hyperfine components distributed among 19 lines. The envelope is approximately Gaussian; the calculated width is ~50 oersteds and independent of concentration. The agreement with experiment therefore appears to be satisfactory.

[1] A. H. Kahn and C. Kittel, Phys. Rev. **89**, 315 (1953).
[2] C. Kittel and E. Abrahams, Phys. Rev. (to be published).

H7. A Calculation of Electron Energy Levels in *F*-Centers.* WILLIAM A. SMITH AND ALLEN B. SCOTT, *Oregon State College* (introduced by Harvey Brooks).—The methods of Simpson[1] have been extended to the calculation of the energies of the 1s and 2p levels for electrons in F-centers of NaCl, KCl, KBr, KI, and of KCl at −194°. The use of a different value of the dielectric constant for NaCl and a more precise evaluation of the parameters λ and β resulted in somewhat better agreement between the observed and calculated energies of maximum absorption than in cases previously reported. The calculations fail to predict a shift of absorption maximum with temperature for KCl, but the observed shift is only 0.08 ev between 20° and −194° and the calculated results generally disagree with observed values by this amount or more. The thermal activation energies necessary to raise electrons from the 2p level to the conduction band were calculated for the four crystals, and ranged from 0.01 ev for KCl to 0.29 for KI. The behavior of F-centers in the four crystals during illumination may be qualitatively correlated with these values.

* This work was supported by the U. S. Office of Naval Research.
[1] J. H. Simpson, Proc. Roy. Soc. (London) **A197**, 269 (1949).

H8. Photoconductivity and *V*-Centers.* K. TEEGARDEN AND R. J. MAURER, *University of Illinois.*—Irradiation of alkali halide crystals with x-rays at −185°C produces a series of absorption bands (V-bands) in the ultraviolet region of the spectrum.[1,2] The V_1 band which occurs at 3600A in KCl and at 4100A in KBr is thermally unstable at higher temperatures. The thermal bleaching of this band is accompanied by the appearance of free charge within the crystal.[3] The V_1 band is also bleached by absorption of radiation at liquid N_2 temperature.[4] Absorption of radiation by the V_1 band is observed to yield negligible photoconductive current at −185°C. Photoconductivity is observed in KBr upon irradiation in the wavelength region between 2500A and 3200A where the V_2, V_4, and V_7 bands occur. KCl shows similar behavior.

* Partially supported by a National Science Foundation Grant.
[1] Casler, Pringsheim, and Yuster, J. Chem. Phys. **18**, 887 (1950).
[2] H. Dorendorf, Z. Physik **129**, 317 (1951).
[3] Dutton, Heller, and Maurer, Phys. Rev. **84**, 363 (1951).
[4] Casler, Pringsheim, and Yuster, J. Chem. Phys. **18**, 1564 (1950).

H9. The Storage of Energy in Silver Activated Potassium Chloride.* C. E. MANDEVILLE AND H. O. ALBRECHT, *Bartol Research Foundation.*—The fluorescence, phosphorescence, and energy storage properties of KCl-Ag have been investigated by noting the behavior of the ultraviolet emission band under alpha-particle bombardment and x-ray irradiation. Particular emphasis is given the study of the release of stored energy by

irradiation with long wave light. The release of the "stored ultraviolet" by photostimulation can be observed only while the stimulating light is on (stimulated fluorescence). There is very little stimulated phosphorescence from KCl-Ag. The storage characteristics of KCl-Ag have been compared with those of NaCl-Ag. The stimulated fluorescence of NaCl-Ag is shown to be much greater than its stimulated phosphorescence, in terms of photons per second. The dosimetric aspects of the data will be discussed.

* Assisted by the joint program of the U. S. Office Naval Research and the U. S. Atomic Energy Commission.

H10. Reversible Bleaching of an Absorption Band of Diamond. PETER PRINGSHEIM, *Argonne National Laboratory.*—When diamonds which show the absorption band in the near ultraviolet, a characteristic of blue fluorescing samples, are exposed to neutron bombardment, a continuous absorption slowly rising toward shorter wavelength is superimposed upon the band. Heating such a diamond to temperatures between 300° and 600°C decreases the continuous absorption and the structure of the band becomes appreciably sharper. Subsequent exposure to light greatly reduces the height of individual peaks in the band, while the continuous absorption at shorter wavelengths is increased. Renewed heating restores the sharp structure of the band and the cycle can be repeated at will. Heating the crystal to 750°C brings the crystal very nearly back into the state before neutron bombardment in which the reversible bleaching cannot be observed. A possible mechanism for this phenomenon will be discussed.

FRIDAY MORNING AT 10:00

Engineering 125

(R. SMOLUCHOWSKI presiding)

Metals

I1. Electron Density in Sodium Tungsten Bronze. W. R. GARDNER AND G. C. DANIELSON, *Iowa State College.*—The electrical resistivity and Hall coefficient measurements of Huibregtse, Barker, and Danielson[1] have been extended to include single crystals of Na_xWO_3 having x values from $x=0.58$ to $x=0.90$. The sodium concentration was determined by comparing the lattice constant with a known lattice constant *versus* concentration curve. A minimum in the resistivity as a function of x was found at $x=0.75$, where $\rho=2.2\times10^{-5}$ ohm-cm, in fair agreement with the results of Brown and Banks.[2,3] The Hall coefficient was found to vary inversely with sodium concentration from $R_H=5.85\times10^{-4}$ cm³/coulomb at $x=0.584$ to $R_H=3.92\times10^{-4}$ cm³/coulomb at $x=0.897$. These results indicate that each sodium atom contributes one conduction electron at any sodium concentration over the entire concentration range. Hence, the anomalous maximum in conductivity at $x=0.75$ must be attributed solely to an anomalous maximum in mobility of the electrons.

[1] Huibregtse, Barker, and Danielson, Phys. Rev. **84**, 142 (1951).
[2] B. W. Brown and E. Banks, Phys. Rev. **84**, 609 (1951).
[3] H. J. Juretschke, Phys. Rev. **86**, 124 (1952).

I2. Thermoelectric Power and Electrical Resistivity of Dilute Solid Solution of Silicon in Copper.* C. A. DOMENICALI AND B. A. BOYD, *Franklin Institute Laboratories.*—We have measured the thermoelectric force against pure copper and the electrical resistivity of Cu-Si alloy wires from −190°C to +600°C, the silicon content varying from 0.1 to 3.9 wt. percent. The relative thermoelectric power against pure copper was always negative and when plotted against Si content has a temperature-dependent minimum of the order of several microvolts/C° at about 1 percent Si at all temperatures within the measured range. The electrical resistivity increases almost linearly with silicon content at all temperatures in the measured range. Matthiessen's rule is fairly well satisfied, the quantity of $d\rho/dt$ increasing from 0.67×10^{-8} ohm cm/C° for pure copper to approximately 1.2×10^{-8} ohm cm/C° for 3.9 percent Si. Chemical analysis of the first set of alloys measured indicated the presence of rather large impurities. A second set was therefore prepared by a completely different technique. The results obtained with the second set agree quite well with those of the first set, considering the smallness of the thermoelectric effects in these alloys; and both agree with the room temperature resistivities found by Norbury in 1926.

* This work was supported by the Signal Corps.

I3. The Debye Temperature of Cu_3Au.* DWAIN B. BOWEN, *North American Aviation, Inc.*—The resistivity of disordered $AuCu_3$ alloy has been measured from 4.2°K to room temperature. From these measurements the Debye temperature has been computed using Gruneisen's formula. There is considerable variation with temperature, but a representative value is 175°. The difference in Debye temperature between this disordered sample, and one partially ordered (heated at 370°C for 50 hours) has been measured by a technique previously described.[1] The Debye temperature has increased on ordering (as might be expected from measurements of elastic constants[2]) by about 10°. Similar measurements will be made on more completely ordered samples. The influence of these Debye temperature changes on the ordering process will be discussed.

* This report is based on studies conducted for the U. S. Atomic Energy Commission under contract AT-11-1-GEN-8.
[1] D. B. Bowen and G. W. Rodeback, Bull. Am. Phys. Soc. **27**, No. 6, G6 (1952).
[2] S. Siegel, Phys. Rev. **57**, 537 (1940).

I4. Hall Effect in Ordered and Disordered Ni_3Mn.* SIMON FONER AND EMERSON M. PUGH, *Carnegie Institute of Technology.*—The two ferromagnetic Hall coefficients,[1] R_0 and α, have been measured in Ni_3Mn for several states of order using fields up to 30 kilogauss. Both R_0 and α are negative in the completely ordered sample ($4\pi M_s\sim9$ kilogauss) and positive in the most disordered sample ($4\pi M_s\sim0.4$ kilogauss). The significance of these data in relation to the band structure, d-band conduction, and electronic specific heat[2] will be discussed.

* Supported by the Office of Naval Research.
[1] Albert I. Schindler and Emerson M. Pugh, Phys. Rev. **89**, 295 (1953).
[2] J. E. Goldman, Magnetism Conference, University of Maryland. September, 1952 [Revs. Modern Phys. **25**, 108 (1935)].

I5. A Dilatometric Study of the Order-Disorder Transformation in Cu-Au Alloys.* W. W. SANVILLE, FOSTER C. NIX, AND FRANK E. JAUMOT, JR., *University of Pennsylvania.*—The order-disorder transformation in Cu-Au alloys in the

composition range from 10 to 32.2 atomic percent Au has been studied by dilatometric means. The interferometric dilatometer and the experimental technique used were similar to those used by Nix and MacNair.[1,2] All samples containing greater than 17.5 atomic percent Au exhibit an anomalous peak in the curve of the coefficient of thermal expansion as a function of temperature. A plot of the critical ordering temperature, T_o, as a function of composition defines an ordered region about 25 atomic percent gold which is in agreement with that defined by resistivity. The coefficient of thermal expansion is rigorously constant above the ordering temperature (to 500°C). The data indicate that the volume expansion is sensitive to small changes in the degree of long-range order, since in all cases the region of anomalous expansion begins at temperatures from 200° to 250°C.

* This work was supported by the Office of Air Research, U. S. A. F.
[1] F. C. Nix and D. MacNair, Rev. Sci. Instr. **12**, 66 (1941).
[2] F. C. Nix and D. MacNair, Phys. Rev. **60**, 320 (1941).

I6. Short-Range-Order in a Cu-Au Alloy.* CHARLES H. SUTCLIFFE AND FRANK E. JAUMOT, JR., *University of Pennsylvania*.—Short-range-order parameters have been measured using x-ray diffraction techniques, at three temperatures above the critical temperature of ordering, for a Cu-Au alloy containing 23 atomic percent gold. The experimental technique used was similar to that employed by Cowley.[1] The diffuse scattered intensity was measured at approximately 900 points within $\frac{1}{2}$ of a unit cell, and corrected for the intensity due to factors other than short-range order. A three-dimensional Fourier analysis was made on the short-range order intensities. The Fourier coefficients are then interpreted as short-range order parameters.[1] The data indicate that an alloy containing less than 25 atomic percent Au exhibits a greater tendency to short-range order than does an alloy at the stoichiometric composition. The tendency to what Cowley has referred to as a "liquid-like" distribution about an origin atom in a Cu_3Au alloy, although present, is considerably less in the 23 percent Au sample.

* This work was supported by the Office of Air Research, U.S.A.F.
[1] J. M. Cowley, J. Appl. Phys. **21**, 24 (1950).

I7. Ordering in the Alloy System Mg-Cd. C. A. WERT, *University of Illinois*.*—A part of the anelastic spectrum of the alloy system Mg-Cd has been investigated. One of the relaxations seen in some of the alloys is believed to be that of "pair-relaxation." This relaxation is particularly interesting in the alloy MgCd, since its magnitude depends on the state of order in the alloy. The damping is small in a well-ordered specimen and relatively high in a disordered specimen. This behavior is consistent with Zener's model for this relaxation. The kinetics of ordering have been studied using the magnitude of the relaxation as a measure of the degree of order. Furthermore, the equilibrium amount of order at some temperatures has been determined, again with the damping as a measure. This technique has not yet been successfully applied to other ordering systems, although some attempts have been made. Indeed, in the system Au-Cu the pair-relaxation itself has not yet been positively identified. It is not yet clear whether this is caused by improper experimental technique or whether the relaxation is actually absent in this alloy system.

* Work sponsored in part by the U. S. Office of Ordnance Research.

I8. The Kinetics of the Disorder-Order Transformation in Cu_3Au. NORMAN W. LORD, *Columbia University*.*—The isothermal order-dependent change in Young's modulus of a single crystal of Cu_3Au is measured as a function of time at various temperatures in the range 279.3° to 384.3°C. These temperatures were reached by quenching rapidly from an equilibrium state 28.2°C above the critical temperature (386.0°C). The time variations of Young's modulus indicate two distinct stages of the disorder-order transformation. The initial stage starts immediately and is completed a few minutes after quenching, while the later stage requires a few minutes before starting and then proceeds very slowly toward an equilibrium state. "Relative relaxation times" are associated with each of them. In conformance with the work of Sykes and Evans and others, the initial stage is described as the formation of contiguous antiphase ordered domains by means of normal atomic interdiffusion. The later stage consists of the coalescence of these domains, and requires at least two different geometrically constrained diffusion processes.

* Present address: Raytheon Manufacturing Company, Waltham, Massachusetts.

I9. The Decay of Vacancies Frozen into an Alloy by Quenching. A. S. NOWICK AND A. E. ROSWELL, *Yale University*.—Measurement of the relaxation time for stress-induced ordering has been used in the study of atomic mobility in substitutional solid solutions both under equilibrium conditions[1] and in the presence of an excess of vacancies frozen in by quenching.[2] These investigations are continued for a silver-zinc solid solution containing 33 atomic percent Zn. Quenching wire of this alloy from 400°C into water traps a vacancy concentration of about 0.01 atom percent. Since relative values of the rate of relaxation, at a given temperature, measure the relative concentration of vacancies present in the alloy, vacancy decay curves are readily obtained. Each plot of the logarithm of the relative vacancy concentration against time (as obtained at 50°, 60°, 70°, and 80°C) is very closely represented by a broken straight line, with a much lower decay rate below the knee or break in the curve. These results indicate that at least two types of imperfections, capable of producing diffusion, are frozen in by quenching.

[1] A. S. Nowick, Phys. Rev. **88**, 925 (1952).
[2] A. S. Nowick and R. J. Sladek, Acta Metallurgica **1** (1953) (to be published).

I10. Change of Optical Constants of Fresh Thin Copper and Silver Films on Exposure to Air. H. Y. LOH AND PETER CHEO,* *Virginia Polytechnic Institute*.—Three optical constants, reflectivity, transmissivity, and absorptivity, of copper and silver films of various thicknesses have been measured in vacuum as soon as the film was made by evaporation on a glass substrate. It was observed that they remained constant in vacuum if undesirable vapor was kept out of the vacuum chamber. But they showed a rapid change immediately on exposure to air at atmospheric pressure. The rate of change decreased in a few minutes, and the later change as observed by Kuhn and Wilson[1] was a very slow one. Copper showed a rapid decrease in reflectivity at the time of exposure. Its transmissivity showed an increase but the change was more gradual than the change of reflectivity. For silver, both reflectivity and transmissivity decreased a relatively small amount as compared with copper. Under low pressure (10^{-4} mm or less) a slight amount of grease vapor was found to cause a tremendous change of the optical constants.

* Now at the State University of Iowa.
[1] H. Kuhn and B. A. Wilson, Proc. Phys. Soc. (London) **B63**, 745 (1950).

I11. The Effect of the Sputtering Rate on the Resistivity and "Aging" of Sputtered Silver Films.* Richard B. BELSER, *Georgia Institute of Technology*.—Data have been collected which shows a definite relation between sputtering rates and initial resistivities of sputtered silver films of 500–1500 angstroms thickness. In a residual argon atmosphere a sputtering current of ten ma gave an initial resistivity of 3.8 times the resistivity of bulk silver, and, for 60 ma, only 1.9 P_b. By heating these films in an infrared oven the values of resistivity were reduced to 1.8 and 1.5 P_b, respectively. This latter value compares favorably with that of silver films deposited by vacuum evaporation and similarly aged. By plotting the ratio

P/P_0 of the films *versus* sputtering current, before and after aging, two curves are obtained which approach each other asymptotically in the region studied. There is evidence, at 10 ma sputtering currents, that resistivity is reduced in accordance with the time the deposition is continued. It appears that heating during deposition, effected by rate or time of sputtering, reduces the initial resistivity of the films. Further drops in resistivity, observed during external heating thereafter, are dependent on the heating occurring during deposition. An explanation is hereby offered for many results described as anomalous in the literature.

* Supported by U. S. Army Signal Corps.

FRIDAY MORNING AT 10:00

Chemistry 116

(W. M. GORDY presiding)

Microwave Spectroscopy

J1. Microwave Spectrum of Trimethyl Chlorosilicane.* RICHARD C. MOCKLER† AND WALTER GORDY, *Duke University.*—Trimethyl chlorosilicane has been found to have a microwave rotational spectrum characteristic of a symmetric top, with $B_0 = 2197.31$ Mc for $(CH_3)_3Si^{28}Cl^{35}$ and $B_0 = 2147.88$ Mc for $(CH_3)_3Si^{28}Cl^{37}$. If tetrahedral angles are assumed with d_{CH} as in methane, the results yield $d_{SiC} = 1.871$A and $d_{SiCl} = 2.029$A. The rotational lines are split into several components by torsional oscillations or restricted internal rotations of the CH_3 groups.

* Supported by Air Research and Development Command.
† Texas Company Fellow. Present address: Department of Physics, Columbia University.

J2. Microwave Spectrum and Structure of Trichlorogermane.* PUTCHA VENKATESWARLU, RICHARD C. MOCKLER,† AND WALTER GORDY, *Duke University.*—Several rotational lines of different isotopic combinations of $HGeCl_3$ have been observed. The B values so far obtained are 2165.78 Mc for $HGe^{74}Cl_3^{35}$; 2169.18 Mc for $HGe^{72}Cl_3^{35}$; and 2172.69 Mc for $HGe^{70}Cl_3^{35}$. Tentative values for the structural parameters are $d_{GeCl} = 2.115$A and $\angle ClGeCl = 108°18'$ with d_{GeH} assumed to be 1.52A.

* Supported by Air Research and Development Command.
† Texas Company Fellow. Present address: Department of Physics, Columbia University.

J3. On the Frequencies of the Microwave Absorption Lines of Oxygen.* MASATAKA MIZUSHIMA, *Duke University.*—It is known[1] that the frequencies of the microwave absorption lines of oxygen do not fit well Schlapp's formula.[2] Examining his theory we found two points to be improved. First we must consider the dependence of λ on N, where λ is the coupling constant of electronic spin and molecular axis and N is the quantum number of end-to-end rotation of molecule. This dependence makes $\nu_+(N-1)+\nu_-(N+1)$ dependent on N, which fit with experimental results, while in Schlapp's original theory it is independent of N. Another point is that Schlapp made a mistake in taking the effect of magnetic interaction between spin and end-to-end rotation of molecule into account. It was found that the improved formula agrees well with the recent experimental data obtained at Duke University. The adopted value of the constants are: $B = 1.4372605\ cm^{-1}$, $\lambda_0 = 1.984627\ cm^{-1}$, $\lambda_1 = 0.000050\ cm^{-1}$, $\mu = -0.008432\ cm^{-1}$, where λ_1 gives the slight dependence of λ on N.

* The work supported by Air Research and Development Command.
[1] Burkhalter, Anderson, Smith, and Gordy, Phys. Rev. **79**, 651 (1950).
[2] R. Schlapp, Phys. Rev. **51**, 342 (1937).

J4. Temperature Dependence of the Line Breadths of Oxygen.* ROBERT M. HILL AND WALTER GORDY, *Duke University.*—Line breadths of several of the millimeter wave lines of O_2 have been measured at $T = 300°$, 195°, and 90°. The results indicate an average temperature dependence of $1/T$ for the line breadth.

* This work supported by Air Research and Development Command.

J5. Microwave Spectrum and Molecular Properties of Ozone.* R. TRAMBARULO,† S. N. GHOSH,‡ C. A. BURRUS, JR.,§ AND W. GORDY, *Duke University.*—Four low J rotational transitions of ozone have been measured between 42 and 118 kmc. These measurements show ozone to be an isosceles triangle with the apex angle of $116°49' \pm 30'$ and with the two equal internuclear distances 1.278 ± 0.003A. The electric dipole moment found from the Stark effect is 0.53 ± 0.02 Debye. Zeeman studies show the molecular g factor to have a strong dependence upon rotational state.

* The work supported by Air Research and Development Command.
† Present address: Department of Physics, The Pennsylvania State College.
‡ On leave from the University of Calcutta.
§ Texas Company Fellow.

J6. Zeeman Effect in the Microwave Spectra of Methyl Fluoride and Methyl Acetylene.* J. T. COX, P. B. PEYTON, JR., AND WALTER GORDY, *Duke University.*—Zeeman splitting or rotational lines of methyl fluoride and methyl acetylene have been measured. The results show that the molecular magnetic field in CH_3CCD is generated primarily by rotation about the symmetry axis ($g_K = 0.31$, $g_N \approx 0$), but that in CH_3F a measurable field is also generated by the end-over-end rotation ($g_N = 0.08$).

* The work supported by the Air Research and Development Command.

J7. The Microwave Spectrum of the Unstable Molecule Carbon Monosulfide. GEORGE R. BIRD* AND RICHARD C. MOCKLER,† *Columbia University.*—The $J = 0 \rightarrow 1$ transitions of $C^{12}-S^{32}$ and $C^{13}-S^{34}$ were observed at $48\,990.55 \pm 0.08$ Mc and $48\,207.038 \pm 0.020$ Mc, respectively. The C−S was produced in an electrical discharge and continuously flowed through a conventional stark cell. Using values for α_e, and D_e, calculated from ultraviolet data[1] the following results were obtained:

$$C^{12}-S^{32},\ B_e = 24\,588.86 \pm 1\ Mc,\ r_e = 1.5347A$$
$$C^{12}-S^{34},\ B_e = 24\,194.90 \pm 1\ Mc,\ r_e = 1.5347A.$$

Mass ratio $S^{34}/S^{32} = 1.06242$. The valve of Be for $C^{12}S^{32}$ determined from ultraviolet spectra is in good agreement with the foregoing value.

* National Research Council Post-Doctoral Fellow.
† Carbide and Carbon Company Post-Doctoral Fellow.
[1] G. Herzberg, *Spectra of Diatomic Molecules* (D. Van Nostrand Company, Inc., New York, 1950), second edition.

J8. On the Quadrupole Moments of Mn^{55}, Re^{185}, and Re^{187}.* A. JAVAN, G. SILVEY, AND C. H. TOWNES, *Columbia University,* AND A. V. GROSSE, *Temple University.*—The quadrupole

coupling constant of Mn^{55} has been measured[1] in MnO_3F, but the Mn^{55} quadrupole moment cannot easily be obtained from this coupling constant because of uncertainties in the structure of the Mn bonds in this molecule. The quadrupole coupling constants of Re^{185} and Re^{187} have now been measured in the structurally similar molecule ReO_3Cl. Since the quadrupole moments of the Re isotopes have been measured from atomic spectra, their values can be used to deduce an approximate value for the quadrupole moment of Mn^{55} if it is assumed that the bond structures of MnO_3F and ReO_3Cl are similar. The result is $Q(Mn^{55}) = 0.5 \times 10^{-24}$ cm^2. This value should be correct in sign and in approximate magnitude. The measurements also confirm spins of $\frac{5}{2}$ for Re^{185} and Re^{187} and give a ratio of the quadrupole moments $Q(Re^{185})/Q(Re^{187}) = 1.06 \pm 0.05$. The quadrupole coupling constant for Re^{185} in ReO_3Cl is 272 ± 6 Mc and for Cl^{35} it is -40 ± 8 Mc.

* Work supported by the U. S. Atomic Energy Commission.
[1] A. Javan and A. V. Grosse, Phys. Rev. **87**, 227 (1952).

FRIDAY MORNING AT 10:00

Biology 113

(PAUL SHEARIN presiding)

Apparatus of Nuclear Physics

JA1. A Van de Graaff Electrostatic Generator.* D. C. SWANSON, *University of Florida.*—A Van de Graaff electrostatic generator, pressure type, has been constructed at the University of Florida. Maximum proton energies of about 1 Mev are expected. The generator has been operated up to about 0.8 Mev at 1 microampere proton beam. A horizontal tripod suspended from the fixed end of the tank supports the sphere, accelerating tube, and charging system. The tank may be rolled back for easy access to the generator for adjustments. The generator is to be used with other equipment now being developed for the study of elastic and inelastic scattering of protons and deuterons.

* This work is being supported in part by the U. S. Atomic Energy Commission.

JA2. 10 Megacycle Radiofrequency Ion Source.* E. W. MCDONALD† AND D. C. RALPH, *Louisiana State University.*—Several modifications of Thonemann[1] type rf ion sources have been employed on a 100-kv Cockcroft and Walton accelerator. The tube base design of Moak *et al.*[2] has been followed. The effects of magnetic field and discharge tube geometry on operating frequency, pressure and power input will be discussed. The discharge tube now in use is 5 cm in diameter and operates at a pressure of about 8 microns. The plate input power to the 10-mc oscillator is 300 to 400 watts. Ion beams of 1.5 ma containing 85 percent monatomic ions are obtained, using either hydrogen or deuterium.

* Supported in part by a grant from the Research Corporation.
† Now at Louisiana College, Pineville, Louisiana.
[1] P. C. Thonemann, Nature **158**, 61 (1946).
[2] Moak, Reese, and Good, Phys. Rev. **83**, 232(A) (1951).

JA3. A High Current 120-Kev Positive Ion Accelerator.* D. L. LAFFERTY, J. A. BIGGERSTAFF, B. D. KERN, AND T. M. HAHN, *University of Kentucky.*—A high current 120-kev positive ion accelerator for fast neutron inelastic scattering studies has been constructed. High voltage is supplied by a Cockcroft-Walton type circuit. The horizontal accelerating tube consists of glass sections and 12 re-entrant aluminum electrodes, sealed together with Vinyl cement, and is 24 inches in length. The 2-inch glass sections for the accelerating tube were cut from 7-inch diameter, $\frac{3}{4}$-inch wall thickness, Pyrex pipe. The ion source is of the radio-frequency type described by Moak *et al.*[1] A well-focused beam of currents up to 500 microamperes and consisting of 90 percent monatomic hydrogen has been obtained.

* Supported by the Office of Ordnance Research, Army Ordnance Corps.
[1] Moak, Reese, and Good, Nucleonics **9**, 3, 18 (1951).

JA4. Performance of a 125-kv Accelerator and Spectrometer. J. BERGSTEIN, *Oak Ridge National Laboratory*, AND R. D. BIRKHOFF, *Oak Ridge National Laboratory and University of Tennessee.*—Particles are accelerated through voltages up to 125 kv by a conventional ion gun and Cockcroft-Walton tube assembly. A second identical tube is used to decelerate the particles through exactly the same potential by connecting the Faraday cage collector electrically to the cathode of the gun. Any energy lost in an absorber placed in the beam is replaced by running the cage at a slightly different potential from the cathode. Differentiation of the current-voltage curve obtained by varying this potential gives the energy distribution of the electron beam. In use with no absorber and 43 kv applied, a distribution 0.2 volt wide at half maximum has been obtained giving a resolution of about 5 parts per million. Experiments contemplated include an investigation of the excitation and ionization produced in matter by the passage of electrons and positive ions, the measurement of W, the average energy required to create an ion pair in various gases for electrons and ions, and electron capture and loss phenomena for positive ions.

JA5. The Oak Ridge 44-Inch Cyclotron. ROYCE J. JONES, *Oak Ridge National Laboratory* (introduced by R. S. Livingston).—A description of the ORNL 44-inch experimental cyclotron will be presented. This proton accelerator is being used in the study of the transmission of ions in a fixed-frequency cyclotron. A discussion of beam composition and beam attenuation will be presented. The use of focusing grids at the entering edges of the dees increases the ion beam current at small radii, but has little effect at the maximum radius. With proper shaping of the accelerating electrode a focusing effect can be introduced in the ion source region which results in a 50 percent increase in beam current at the maximum radius. A proton current of three milliamperes at 1.5 Mev has been obtained with the ion source described previously.* A deflected beam of 380 microamperes has been measured.

* Livingston, Jones, and Wright, Phys. Rev. **78**, 329 (1950).

JA6. Electromagnetic Shims for Focusing in a Fixed-Frequency Cyclotron. FARNO L. GREEN, *Oak Ridge National Laboratory* (introduced by R. S. Livingston).—The conventional type of iron shims, used for focusing, in the ORNL 44-inch experimental cyclotron (Abstract JA5) has been replaced by electromagnetic shims for studies of magnetic focusing of the beam. Various magnetic field configurations and gradients are easily examined with a great saving of time

and labor. The statement[1,2] that magnetic focusing is of little effect at small radii but is very effective at large radii was verified experimentally. It was shown that for 1.5-Mev protons a linear magnetic field drop-off of two percent along the median plane, radially outward to maximum beam radius, gives optimum beam focusing as indicated by maximum beam intensity. This type of focusing shims has proved to be practical during many months of cyclotron operation.

[1] M. E. Rose, Phys. Rev. **53**, 392 (1938).
[2] Robert R. Wilson, Phys. Rev. **53**, 408 (1938).

JA7. Cyclotron Efficiency and Power Distribution Measurements. A. L. BOCH AND E. D. HUDSON, *Oak Ridge National Laboratory* (introduced by R. S. Livingston).—The high beam power obtained with the ORNL 86-inch cyclotron prompted an experimental study of the power distribution and the efficiency of the machine. As measured calorimetrically, the power transmitted to the internal target by 22-Mev protons has exceeded 60 kw. Power to the target is limited by thermal properties of the target and the available power in the rf system; under off-resonance conditions, over 40 milliamperes of ions can be made to circulate in the dees at an average energy of approximately 2 Mev. The dc isolation of the dees has made it possible to determine the ion losses to the dees for both on- and off-resonance conditions; a power distribution method is used in obtaining the average energy of the ions. For proton currents exceeding 1500 microamperes the target power is over 10 percent of the power input to the oscillator, the ion transport efficiency approaches 15 percent, and the target power is over 50 percent of the total ion loading of the rf system.

JA8. Radioisotope Production in the ORNL 86-Inch Cyclotron. J. A. MARTIN, *Oak Ridge National Laboratory* (introduced by R. S. Livingston).—A proton current in excess of one milliampere at an energy of 22 Mev is available on internal targets in the ORNL 86-inch cyclotron. Currents of this magnitude and at this energy make possible the relatively large-scale production of a number of radioisotopes which cannot be produced in nuclear reactors. The (p, n), $(p, 2n)$, and (p, pn) reactions give comparatively high yields. The yields for several radioisotopes are given. For example, Be^7 is produced by the (p, n) reaction on Li^7 at a yield of 160 millicuries per milliampere-hour; lithium-coated targets have been developed which allow proton currents as high as 600 microamperes to be utilized. Ga^{67} is obtained from both the (p, n) reaction on Zn^{67} and the $(p, 2n)$ reaction on Zn^{68}; from a zinc target, in which the abundance of these two isotopes is 4.1 percent and 18.6 percent, respectively, a yield of 600 millicuries per milliampere-hour is obtained.

JA9. A Measurement of the Neutron Energy Distribution in the ORNL Graphite Reactor. JAMES B. TRICE (introduced by J. H. Crawford, Jr.).—Analyses of many radiation damage experiments require that the energy distribution of the bombarding neutrons be known. This can be accomplished in some cases by using *nuclear threshold detectors* to measure the energy distribution above one Mev and *nuclear resonance detectors* for lower (or epithermal) energies. Such a scheme has been used to examine the neutrons at a certain location in the ORNL graphite reactor. For the high energy component of the spectrum, the nuclear threshold detectors, together with their respective threshold energies are $Cl^{35}(n, \alpha)P^{32}$ at 0.5 Mev, $P^{31}(n, p)Si^{31}$ at 2.4 Mev, $Al^{27}(n, p)Mg^{24}$ at 4.6 Mev, and $Al^{27}(n, \alpha)Na^{24}$ at 8.1 Mev. For the lower energy component of the spectrum an inverse dependence on energy ($\sim 1/E$) was found using Mn^{55} and Na^{23}, which have (n, γ) cross section resonances at 261 ev and 1710 ev, respectively. The neutron spectrum was thus found to consist of principally two components; a strong so-called "fission" group of neutrons in the energy interval 1 to 10 Mev and a group of lower energy (epithermal) neutrons with an energy distribution inversely proportional to energy.

JA10. A Terphenyl-Boron Liquid Neutron Detector.* W. H. CAMPBELL AND J. I. HOPKINS, *Vanderbilt University*.—The scintillation properties of various concentrations of *p*-terphenyl dissolved in *p*-toluene were studied for maximum pulse size response to conversion electrons with a view of possible use in conjunction with ethyl borate as an efficient neutron detector. A suitable cell with a plastic window above a 5819 photomultiplier tube was used with a single-channel pulse-height analyzer to obtain count-rate *versus* pulse-height data. The response of the scintillation solutions to a Po-Be neutron flux was investigated before and after ethyl borate was added. The best response to date has been obtained by adding an 8 g/l solution of *p*-terphenyl in *p*-toluene to an equal volume of ethyl borate. The results thus far for this neutron detector indicate that the count-rate *versus* pulse height can be represented by an equation of the form

$$(n/t) = C_1[1 - C_2 e^{-C_3(PH)}].$$

* Work supported by the U. S. Atomic Energy Commission.

JA11. A Differential Pulse-Height Discriminator.* R. C. SHRECKENGOST, D. C. SWANSON, AND J. W. FLOWERS, *University of Florida*.—A relatively simple differential pulse-height discriminator designed to operate with pulses in the order of one microsecond in length and to one hundred volts in amplitude has been developed for use in scintillation spectroscopy. The discriminator employs differentially biased blocking oscillators with window widths to ten volts. The minimum amplitude bias and window widths can be easily adjusted to 0.1 percent of their respective ranges.

* This work was supported in part by the U. S. Atomic Energy Commission.

JA12. The Characteristics of an Allen Type Electron Multiplier. C. F. BARNETT, *Oak Ridge National Laboratory*.—In experiments being conducted at Oak Ridge National Laboratory it is necessary to have a particle detecting instrument sensitive to positive ions of various masses ($1 \leq A \leq 40$) and energies in the 3–200 kev range which can be used either as a single particle counter or a current measuring device for input currents up to 10^{-12} ampere. The characteristics of an Allen type electron multiplier have been studied to determine the feasibility of its use for this purpose. Results will be presented giving the gain of the multiplier as a function of input current, pressure, and multiplier voltage. Also, the gain as a function of mass and energy will be discussed, as well as the stability of the gain with time. With the first dynode at a potential of negative 5 kv the gain increases practically linearly for H_2^+ ions with energy in the range 3–10 kev. At an energy of 5 kev the secondary emission produced at the first dynode by molecular ion (e.g., N_2^+) is larger than that produced by atomic ions of comparable masses (e.g., Ne^+). It has been concluded that the stability and gain of the electron multiplier is sufficient to justify its use as a quantitative ion detector.

JA13. Gradation Development Method for Nuclear Emulsions. H. G. DECARVALHO, V. DAVIS, AND W. TESH, *North Carolina State College*.—A method is described for the technique of critical development of emulsions in which it is desired to identify ionizing particles. A test strip is first developed with a solution of graded concentration. From this strip the optimum concentration of developer is determined. The optimum concentration is then used with graded time to complete the development. Using plates loaded with boron and lithium and exposed to neutron flux, one is able to discriminate between alpha-triton and alpha-lithium tracks and to measure their lengths readily.

FRIDAY MORNING AT 10:00

Physics 114

(TURNER ALFREY, JR., presiding)

Division of High-Polymer Physics

Symposium on Crystallization in Polymers

K1. Opening Remarks. TURNER ALFREY, JR., *Dow Chemical Company.* (20 min.)
K2. Equilibrium Theory of Crystallization. P. J. FLORY, *Cornell University.* (30 min.)
K3. Kinetics of Crystallization. LEO MANDELKERN, *National Bureau of Standards.* (30 min.)
K4. Recent Work on the Structures of Crystalline Polymers. C. W. BUNN, *Imperial Chemical Industries.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Physics 114

(TURNER ALFREY, JR., presiding)

Division of High-Polymer Physics

Symposium continued from Session K

L1. X-Ray and Infrared Studies on the Extent of Crystallization. J. B. NICHOLS, *Du Pont Experimental Station.* (30 min.)
L2. Relations Between Crystallization and Second-Order Transition. R. F. BOYER, *Dow Chemical Company.* (30 min.)
L3. Molecular Structure and the Crystallizability of Polymers. C. W. BUNN, *Imperial Chemical Industries.* (30 min.)

(R. F. BOYER presiding)

Contributed Papers

L4. Orientation in Polymeric Films by Infrared and X-Ray Techniques. W. H. COBBS, JR., S. B. COLE, AND R. L. BURTON, *E. I. du Pont de Nemours & Company* (introduced by W. E. Mochel).—Methods have been evolved for quantitative estimation of degree of orientation of polymeric films by a Weissenberg x-ray technique and by absorption of polarized infrared light. Both axial orientation and uniplanar orientation may be determined in each method. The results from the x-ray method apply only to the crystalline part of the polymer, whereas those from infrared include in addition to a crystalline part a contribution from the amorphous regions. Results from both methods are in general agreement; in certain cases differences can be interpreted in terms of the relative importance of the crystalline and amorphous portions in oriented polymeric materials.

L5. Crystallization in Butadiene-Styrene Copolymers.* LAWRENCE A. WOOD, *National Bureau of Standards.*—Butadiene-styrene copolymers contain the following units: *trans*-1,4-polybutadiene, *cis*-1,4-polybutadiene, 1,2-polybutadiene, and polystyrene. Of these the first is the only type which has been shown by x-ray evidence to form crystals. An examination is made of the consequence of the hypothesis that crystallization in these copolymers in a given time at the optimum temperature requires a certain minimum content of *trans*-1,4 units, independent of the relative amounts of the other three types. Lines of constant *trans*-1,4 content are plotted on a graph with the content of polystyrene units as abscissa and the proportion of *trans*-1,4 units with respect to total polybutadiene content as ordinate. A similar family of curves can be plotted with the temperature of polymerization as ordinate. According to the hypothesis one of the curves will mark the boundary between the region of possible crystallization and the region in which crystallization will not be noted in the given time. Dilatometric and calorimetric studies of the crystallization within about 3 hours at −45°C yield experimental points which conform quite well to the curve for a *trans*-1,4 content of about 58 percent. The fact that the points fall on a single curve appears to give substantial support to the hypothesis.

* Supported in part by the U. S. Office of Naval Research and the Office of the Quartermaster General.

L6. The Melting Transition of Natural Rubber.* DONALD E. ROBERTS AND LEO MANDELKERN, *National Bureau of Standards.*—The statistical thermodynamic theory[1] of semicrystalline polymers has led to the concept of an equilibrium melting temperature, T_m, the temperature at which crystallinity disappears completely. This temperature is characteristic of a given polymer and independent of previous thermal history. The well-known results for natural rubber[2] where the melting temperature is strongly dependent on the crystallization temperature are not in accord with these conclusions, and has been reinvestigated. The melting temperatures of two molecular weight fractions and a third sample of purified rubber hydrocarbon were determined, as a function of crystallization temperature, using dilatometric techniques. After crystallization at −18°C, 0°C, and +8°C, on subsequent slow heating,

the melting temperatures all occurred in the range 22° to 23°C, irrespective of the crystallization temperature. A slow heating rate is important in order to allow imperfect crystallites to reform into a more stable arrangement; if a fast heating rate is employed, results similar to those previously reported[2] are obtained. However, after crystallizing at +14°C and heating slowly, the melting temperatures occur in the range 27° to 28°C. Thus, the effect of the crystallization temperature on the melting temperature is considerably smaller in magnitude than previously thought.

* Assisted by the U. S. Office of Naval Research and Office of the Quartermaster General.

[1] P. J. Flory, J. Chem. Phys. **17**, 223 (1949).

[2] L. A. Wood and N. Bekkedahl, J. Appl. Phys. **17**, 362 (1946); J. Research Natl. Bur. Standards **36**, 489 (1946).

L7. An Infrared Study of the Crystallization of Polyethylene. ALEXANDER BROWN AND F. P. REDING, *Carbide and Carbon Chemicals Company.*—The melting points and the temperatures for the onset of crystallization of a series of polyethylene resins covering a variety of molecular weights and degrees of chain branching have been determined by observing the 13.7-micron crystallinity band of the infrared spectrum. An increase in the amount of chain branching decreases the melting point considerably whereas a decrease in the molecular weight, at least in the range studied, lowers the melting point only slightly. On the other hand an increase in chain branching decreases, but a decrease in molecular weight apparently increases, the temperature at which crystallization starts at any given rate of cooling. The rate of crystallization of polyethylene as a function of temperature, chain branching, and molecular weight will also be discussed. In the temperature range studied the rate increases markedly with a decrease in temperature and a decrease in the amount of chain branching.

FRIDAY AFTERNOON AT 2:00

Chemistry 116

(W. G. POLLARD presiding)

Invited Papers in Nuclear Physics

M1. The Raleigh Research Reactor. C. K. BECK, *North Carolina State College.* (30 min.)

M2. Progress in Reactor Physics and Reactor Technology. A. M. WEINBERG, *Oak Ridge National Laboratory.* (30 min.)

M3. Polarized Photons. F. L. HEREFORD, *University of Virginia.* (30 min.)

M4. Production of Polarized Particles in Nuclear Reactions. ALBERT SIMON, *Oak Ridge National Laboratory.* (30 min.)

M5. Nuclear Reactions with He^3 Nuclei. W. M. GOOD, *Oak Ridge National Laboratory.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Page Auditorium

(W. M. GORDY presiding)

Southeastern Section of the American Physical Society

Programme on the Teaching of Physics

Invited Paper

N1. Responsibilities and Training of Physics Teachers. T. H. OSGOOD, *Michigan State College.* (30 min.)

Contributed Papers

N2. The Teaching of Biophysics. DAVID POMEROY, *Army Medical Research Laboratory, Fort Knox.*—In a discussion on the present status of biophysics[1] the problem was considered largely from a thermodynamic standpoint. It must be conceded, however, that there is a large, growing need to adopt mathematical and physical methods also to problems of biological effects of radiations. The subject may be classified under 3 headings. 1. *Radioactivity.*—Natural and artificial radioactivity; the elementary particles; measurement of half-lives; activity in curies; uses of radioisotopes in biology and medicine. 2. *Passage of radiation through matter.*—Ionization; range-energy relations; stopping power; photoelectric effect; Compton effect; pair production; neutron capture; the intermediate nucleus; nuclear disintegrations; methods for detection and counting of elementary particles; statistics of counting. 3. *Action of radiation on living cells.*—Dosimetry as defined in different types of roentgens; modes of biological and chemical effects; target theory; inactivation of viruses, rickettsia and bacteria; mutations; carcinogenesis and treatment of cancer.

[1] Science **113**, 617 (1951).

N3. Sharp Shadows as "Images." E. SCOTT BARR, *University of Alabama.*—A local eye specialist, Dr. Harvey B. Searcy, found that it is possible to show a patient a cataract or certain other defects of his eye very simply. The patient takes a converging lens of about 6 diopters and looks through it at a distant point source of light. The patient then sees his

cataract clearly imposed upon the bright field. The explanation lies in the fact that this procedure results in making the posterior focal point of the lens coincide with the anterior focal point of the eye. Consequently, the light is essentially parallel after entering the eye, and sharp shadows of any obstructing areas are projected on the retina. The retinal response is such that these shadows are interpreted as images (inverted, of course). The confusion of sharp shadows with images may also arise in optical bench experiments when a bright point source (such as the Western Union arc) is used to illuminate a wire screen as an object. This may lead to the surprising effect that covering the top half of the lens results in the loss of the top half of the "image."

N4. An Experiment with Transistors for the Elementary Electronics Laboratory Course. F. H. MITCHELL, *University of Alabama.*—A simplified experiment using point-contact transistors is described. After the collector volt-ampere family of curves is obtained, a single-stage grounded-base amplifier is designed and built. Its band width and degree of distortion are measured, and the current gain calculated. Next, a sine-wave feedback oscillator of a type selected by the students is constructed, and its stability and range of adjustable audio frequencies is measured. Finally, an assignment is given to construct an amplifier or an oscillator of good quality using a minimum of components, weight, and space. The results obtained by the several groups of students in this miniaturization are compared, and a winner is chosen by vote of the entire class. A considerable rivalry is like to accompany this assignment.

N5. A Classical Neutron Model. ARTHUR E. RUARK, *University of Alabama.*—Students sometimes inquire whether there is a convenient neutron model, a companion to the Lorentz surface-charged electron. The electrical potential $V_0 \exp(-r^2/a^2)$ leads to such a model. It corresponds to a charge-density $(V_0/4\pi a^2)(6-4r^2/a^2)\exp(-r^2/a^2)$. The total charge is zero. The electrostatic energy is $Mc^2 = (9\pi/512)^{\frac{1}{2}} a V_0^2$. This model usually incites lively arguments.

N6. Electrolysis of Water: An Experiment in Atomic Physics. CARL C. SARTAIN, *University of Alabama.*—If one measures the current I and the time t required to liberate a mass M of oxygen collected at pressure p and volume v and at absolute temperature T, he can determine seven important physical constants. They are the Faraday F, the mass m of an oxygen atom, the mass of one atomic mass unit, Avogadro's number N_0, Boltzmann's constant k, the universal gas constant R, and the volume V of one mole of gas at standard conditions. One needs to have measured the charge on the electron (oil drop method) or be willing to accept the value of that charge.

N7. Is it Possible to Teach Physics to Humanities Students? N. GOLDOWSKI, *Black Mountain College.*—During the years following the end of the war, physics gradually became a compulsory rather than an elective subject, not only for science students but also for those in liberal arts. The necessity of acquainting humanities students with physics was voiced by many, including this writer. The reason for teaching physics can be expressed by the saying: "man has to know the world he lives in." The understanding of the world seems to be based on the laws and concepts of physics. Teaching physics to mathematically virgin students became a problem, for which several solutions were offered. Essentially, most of them lead to teaching *about* physics, in order to avoid mathematics, the language of physics. It now appears questionable whether teaching about physics provides a knowledge of physics or an understanding of the underlying concepts. It is proposed to teach physics with emphasis on concepts but without translating the language of physics—mathematics—into everyday language, so as to give the student "first hand" experience in science.

N8. Graduate Training for High School Physics Teachers and Cooperation between College and High School Physics Departments. DONALD C. MARTIN, *Marshall College.*—A report of a study made, especially in the Southern states, to determine what is being done by colleges in the way of providing graduate programs in physics for high school teachers, and also what colleges are doing in the matter of cooperating with high school physics departments such as loaning equipment, faculty members presenting demonstration lectures at high school assembly programs, giving assistance to science clubs, and discussing opportunities of a career in physics with high school seniors.

N9. Incentive Grading for the Basic Laboratory Reports. RAY M. MORRISON, *Combustion Engineering Corporation,* AND M. S. MCCAY, *University of Chattanooga.*—The success of incentive wage systems in industrial operations suggests potential benefits from a similar plan in the basic physics laboratory. Blind dependence upon vague, negative grading practices, such as "an average, complete report rates B," can hardly be expected to develop student interest, initiative, accuracy, and thoroughness. On the other hand, nondiscriminating assignment of high grades to all reports encourages carelessness and lack of respect for the course work. In view of the demand on modern colleges for finished products with superior qualities in laboratory (1) experimentation, (2) communication, and (3) initiative it would seem to be scientific to give more attention to quality control of the student product during the production process. Specifically, this study is concerned with the developing and testing of a check list of essential laboratory report features, which serves both as a positive system for determining report grades, and as a constructive guide to incentive-minded students.

FRIDAY AFTERNOON AT 2:00

Engineering 125

(A. H. NIELSEN presiding)

Mostly about Crystals

O1. Vibration Spectrum of a Simple Cubic Lattice.* GORDON F. NEWELL, *University of Maryland.*—Analytic expressions are derived for the frequency distribution function $g(f)$ of a simple cubic monatomic lattice. Only nearest and next-nearest neighbor interactions are considered and the latter are assumed to be weak compared with the former.

The procedure is based upon considering the next-nearest neighbor interactions as a perturbation and the results are correct to the first power of a parameter τ which is essentially a measure of strength of the next-nearest neighbor forces as compared with the nearest neighbor forces. It has been known for some time that the problem with nearest neighbor interactions only degenerates into the equivalent of three one-dimensional problems giving a nonzero $g(f)$ for $f=0$ and an infinite value at the maximum frequency. If, however, one includes even a small interaction between next-nearest neighbors, the behavior of $g(f)$ near both ends of the spectrum changes considerably, in fact it vanishes at both ends. In between these points $g(f)$ is continuous but has four analytic singularities with vertical tangents of the type predicted by van Hove for a quite general type of crystal.

* Partially supported by the U. S. Office of Naval Research.

O2. Dislocations and Edge States in the Diamond Crystal Structure. W. SHOCKLEY, *Bell Telephone Laboratories.*—Dislocations in the diamond structure are somewhat more complicated than those usually considered: An edge, or Taylor's dislocation, with slip vector on a (111)-plane may have its extra half-plane of atoms terminate with broken bonds parallel either to [111]-direction or at tetrahedral directions thereto. In the former case, separation into partial dislocations is impossible whereas in the latter it may occur at the expense of next-next neighbor distrubances only. At the edge of the extra half-plane there may be a one-dimensional band of "edge-states" analogous to two-dimensional surface state bands. As for surface states[1] there are conditions in which these edge states may be partially filled thus causing each dislocation to become a one-dimensional degenerate-electron-gas conductor. Depending upon "work function," such dislocation arrays could form *n*- or *p*-type grain boundaries and make boundaries behave like surface states rather than extrinsic regions.[2] They might also contribute to the anomalously large nonlinear conductivities observed at very low temperatures.[3]

[1] W. Shockley, Phys. Rev. **56**, 317 (1939).
[2] G. L. Pearson, Phys. Rev. **76**, 459 (1949) and Taylor, Odell, and Fan, *ibid.* **88**, 867 (1952).
[3] C. S. Hung and J. R. Gleissman, Phys. Rev. **79**, 726–728 (1950); R. C. Fletcher (personal communication).

O3. Electrical Breakdown Path Orientation in Alkali Halide Crystals. J. W. DAVISSON, *Naval Research Laboratory.*—The general idea of a fast electron scattering mechanism involving Brillouin zone boundaries, conceived by A. von Hippel, has been used by E. L. Offenbacher and H. B. Callen[1] in a quantitative calculation of electrical breakdown path orientation. This calculation predicts a sequence of breakdown directions in alkali halide crystals with increasing temperature consisting of (random:100:111:110 and 100:100). The theoretical treatment does not include the *xxy* star paths which have now been observed in KF and NaCl as well as in the lithium halides.[2] The data suggest that the star patterns appear when the probability for breakdown in 110 and 111 is equal, or nearly so. Experimental observations give the sequences (random:100:*xxy**:110) for K and Rb halides, (random:100*:111:*xxy**:110) for Na halides, and (*xxy**:110:*xxy*:111:110) for the Li halides. The starred orientations above are unstable.

[1] E. L. Offenbacher and H. B. Callen, Phys. Rev. **83**, 227 (1951).
[2] J. W. Davisson, Phys. Rev. **70**, 685 (1946) and **73**, 1194 (1948).

O4. Electron Motion in Polar Crystals. E. P. GROSS, *M.I.T.*—The energy levels of the system consisting of an electron interacting with the longitudinal optical modes of frequency ω in a polar crystal are studied in detail by the method of Fock configuration space.[1] For the lowest levels and for small coupling strengths the energy and effective mass agree with the linear dependence on coupling predicted by the intermediate coupling theory.[2] Deviations in the direction of higher effective masses are found with increasing interaction strengths. For states of energy $\approx\hbar\omega/2$ above the ground state the effective mass is greater than it is for the lowest levels. The depression of the energy continuum of the levels which for zero coupling lies at an energy $\hbar\omega$ is computed as a function of interaction strength.

[1] E. P. Gross, Phys. Rev. **88**, 153 (1952).
[2] T. D. Lee and D. Pines, Phys. Rev. **88**, 960 (1952).

O5. Electronic Energy States of Impurities in Nonmetallic Crystals. KURT LEHOVEC, *Sprague Electric Company.*—The potential around an impurity in a crystal can be divided into two parts: (1) Within a sphere with the radius of the impurity the potential approaches the core potential of the free impurity (except of an additive constant), (2) outside of this sphere the potential is the periodic lattice potential with a superimposed Coulomb-like field determined by the effective charge of the impurity and the lattice polarization. Accordingly two types of wave functions for an electron attached to the impurity can be distinguished: (1) ψ_1 functions resembling orbitals of the impurity in free space and located nearly entirely within the sphere mentioned above; (2) ψ_2 functions resembling hydrogen-like orbitals, extending far beyond the sphere. A crude criterion on the existence of ψ_1 functions is based on (a) energy levels of the free impurity and lattice energy, or (b) on the radius of the free impurity and the space available in the lattice. ψ_1 functions do not exist in covalent crystals [e.g., Ge(Sb)], but may exist in ionic crystals [e.g., KCl(Tl)]. ψ_2 functions exist always. A ψ_1 function, if existing, represents the ground state, whereas ψ_2 functions represent excited states. The significance of the (ψ_1, ψ_2) state for a two-electron problem (ZnS with interstitial Cu) will be discussed.

O6. Density Changes in Glass During Heat Treatment. H. N. RITLAND, *Corning Glass Works.*—The structure of glass is known from x-ray diffraction studies to have a random character similar to that possessed by liquids. In common with liquids, glass has an equilibrium structure that is a function of temperature. At temperatures near the annealing point, about an hour is required for equilibrium to be reached; the time increases rapidly as the temperature is lowered. This loosely defined range of temperature in which physical properties can be observed to vary with time is called the transformation range; room temperature properties of glass are dependent on previous thermal history in the transformation range. The effect of heat treatment on the room temperature density and refractive index of a boro-silicate crown glass has been studied. Data will be presented on the variation of density with length of treatment at a constant temperature in the transformation range and on the approach of the density to its asymptotic value during cooling through this range at a constant rate. These will be discussed in connection with the concept of fictive temperature, in which the state of the glass is characterized by the temperature in the transformation range at which that state would be in equilibrium.

O7. Crystallite Size and Diamagnetic Susceptibility of Carbons.* H. T. PINNICK, *University of Buffalo.*—Single graphite crystals have an anomalously large susceptibility in the *c*-direction (principal axis), while the susceptibility in the aromatic plane is much smaller and of the same order of magnitude as for all hydrocarbons (including the condensed aromatic molecules). In order to get information about the nature of the changes occurring when condensed aromatic molecules grow and transform into graphite crystals, carbons with intermediate range of crystallite sizes were investigated. Purified carbon rods were heat-treated to different temperatures to get a wide variation in crystallite sizes. Furthermore, a number of carbon blacks with particle sizes from 50A to

3000A were all heat-treated to 3000°C; since the particle surfaces limit the growth of crystallites a range of well defined sizes was obtained. The crystallite dimensions were determined from the broadening of x-ray diffraction lines and the susceptibilities measured at room temperature using Gouy balance. When the gram susceptibilities are plotted as a function of the crystallite diameter d ("a" direction), the experimental points lie scattered around a single curve, in which almost all of the increase from $\chi=-0.5\times10^{-6}$ to about -6×10^{-6} occurs in the interval for d from 50A to 150A. The deviations from the average curve are probably caused by differences in origin and history of the individual samples.

* Supported in part by the U. S. Office of Naval Research.

O8. Computations of Three-Dimensional Structure Factors on S-FAC.* R. PEPINSKY AND P. F. EILAND, *The Pennsylvania State College.*—S-FAC was constructed to compute structure factors corresponding to a two-dimensional array of twenty atoms in the asymmetric unit of a crystal cell. Five types of atoms (i.e., different f curves) can be accommodated at one time. The $(x_1^{(n)}, x_2^{(n)})$ coordinates are established as desired by means of two potentiometers for each atom, the atomic centers appearing on the X-RAC 'scope as movable marker pips; and the FH_1H_2 values appear as meter readings. Coordinates can be altered at will to permit instantaneous examination of agreement between observed and calculated structure-factor amplitudes. A computation rate of ten FH_1H_2 values per minute is readily attained. Three-dimensional factors can be readily computed, while maintaining the mobility of trial atomic positions, by ganging an additional set of twenty potentiometers to produce dc outputs corresponding to $\cos2\pi H_3x_3^{(n)}$ and $\sin2\pi H_3x_3^{(n)}$ values. These modulate the f_n values to permit immediate computation of the function

$$\begin{aligned}FH_1H_2H_3=\sum_{n=1}^{N} f_n\left(\frac{\sin\theta}{\lambda}\right)[&\cos2\pi(H_1x_1^{(n)}+H_2x_2^{(n)})\cos2\pi H_3x_3^{(n)}\\&-\sin2\pi(H_1x_1^{(n)}+H_2x_2^{(n)})\sin2\pi H_3x_3^{(n)}\\&+\sin2\pi(H_1x_1^{(n)}+H_2x_2^{(n)})\cos2\pi H_3x_3^{(n)}\\&+\cos2\pi(H_1x_1^{(n)}+H_2x_2^{(n)})\sin2\pi H_3x_3^{(n)}].\end{aligned}$$

One layer-line (H_3 value) at a time is computed, the $H_3x_3^{(n)}$ values being fed to the new set of potentiometers.

* Development supported by the U. S. Office of Naval Research.

O9. An Iteration-Variation Calculation of the Electronic Structure of Diamond.* M. DANK AND H. B. CALLEN, *University of Pennsylvania.*—The integral iteration method[1] for obtaining the solutions of the Hartree-Fock equations has been improved by the incorporation of variational stages alternating with the iterations. The resulting rapidly convergent technique has been applied, for the purpose of testing its feasibility, to the calculation of the width of the valence band and of the gap width between the top of the filled band and the lowest s-state in the conduction band of diamond. With only three iterations, these computed energies are respectively 27.9 ev and 17.8 ev. The experimental value for the former is approximately 18 ev, whereas the most reliable available value for the latter[2] is 14 ev. The method of successive iteration and variation (SIAV) appears on this basis to be more convenient than the Wigner-Seitz method.

* Research supported by the U. S. Office of Naval Research.
[1] M. Dank and H. B. Callen, Phys. Rev. **86**, 622(A) (1952).
[2] F. Herman, Phys. Rev. **88**, 1210(L) (1952).

O10. Luminescent Effects in Chemically Pure ZnO.* T. TODD REBOUL, *University of Pennsylvania.*—Pills of ZnO, sintered from spectroscopically pure powder, have been examined at various temperatures for luminescent properties when excited by x-rays. The 395 millimicron luminescent peak has a decay $<10^{-6}$ second at all temperatures between 100°K and 300°K; the 510 millimicron peak which is about 10 times more intense than the 395 peak at 100°K has a decay which changes from about 4×10^{-4} second at 125°K to a microsecond at room temperature. Thermoluminescence experiments show that only the 510 millimicron peak is emitted during the heating process and that its temperature of peak emission is not dependent on excitation but does depend upon heating rate going from 137°K at 1.6°K per minute to 154°K at 18°K per minute. From this heating rate-peak temperature data, the activation energy of the traps responsible for the thermoluminescence is found to be 0.24 ev. It was not possible by examining the slope of the log decay time *versus* reciprocal temperature curve to find a value for activation energy consistent with the value found by the thermoluminescence experiments.

* Supported by the U. S. Office of Naval Research.

O11. Adsorbed Oxygen in Zinc Oxide Photoconductivity.* DONALD A. MELNICK AND LEO J. NEURINGER, *University of Pennsylvania.*—It is believed that adsorbed oxygen influences the photoconductivity of sintered zinc oxide. The oxygen atoms capture conduction electrons in the "necks" which connect the sintered grains. These necks, which account for most of the sample's resistance, have a surface to volume ratio sufficiently high to make this electron capture significant. Studies have been made of the process of rise and decay for times up to 10^6 seconds, with a resolution of $\frac{1}{4}$ second. (Over 95 percent of the change occurs in times greater than $\frac{1}{4}$ second.) The plot of photoconductivity *vs* log time shows continuing changes over this entire period of time, and shows only gradual changes in slope. It is therefore impossible to resolve the process into a small number of discrete time constants, but rather it is suggested that there is only one process, which is presumably associated with the adsorption and desorption of oxygen. The rate of decay increases considerably with the pressure of the ambient air. It has been determined experimentally that the effective agent in air is oxygen.

* This work supported by the U. S. Office of Naval Research.

FRIDAY AFTERNOON AT 2:00

Biology 113

(W. SHOCKLEY presiding)

Semiconductors, II

P1. Deuteron Irradiation of Germanium Near Liquid Nitrogen Temperature.* J. H. FORSTER, H. Y. FAN, AND K. LARK-HOROVITZ, *Purdue University.*—Bombardment by 9.3-Mev deuterons (at about 100°K) converted an n-type germanium sample (1.62 mho-cm^{-1}) to p type (1.2×10^{-6} mho-cm^{-1}) and decreased the conductivities of two p-type samples (93.8 and 10.5 mho-cm^{-1}) to 7.75×10^{-6} and 9.7×10^{-7} mho-cm^{-1}, respectively. At the beginning of bombardment the decrease

of holes per deuteron is 2.6 and 0.42 in the p-type samples. Mobilities measured at 90°K (about 10 cm²/volt-sec) are lower than values observed in any chemically doped p-type samples. When bombarded samples are raised to different temperatures T, the resistivity ρ and the Hall coefficient R change with time at a rate depending on T. For $T<141$°K, R and ρ increase, whereas $T>149$°K they decrease. After some time at each T, ρ, and R, curves can be taken reproducibly between T and 77°K. Most curves show two slopes in semi log plot against $1/T$. It follows that defects produced by bombardment undergo changes at relatively low temperatures. The temperature changes after bombardment and the $\sigma(\Phi)$ curves during bombardment are difficult to explain by changes in the concentration of introduced localized levels, without changing their distribution. A possible explanation is clustering of defects.

* Supported by Signal Corps contract.

P2. Germanium Films II.* W. M. Becker and K. Lark-Horovitz, *Purdue University.*—Germanium films were deposited on heated quartz plates by the thermal dissociation of GeH_4. X-ray measurements indicate the normal diamond lattice, with particle sizes >2000A, far larger than the particle sizes found in evaporated films. Film thicknesses ranged from <0.1 microns to 1.5 microns. Hall constant and resistivity were measured as a function of temperature. Log ρ and $\log|R|$ *versus* $10^3/T$ curves differ from similar plots for bulk germanium. Mobilities are lower than usually found for bulk germanium. All of the films made by thermal dissociation of GeH_4 were p type at room temperature. A region of conductivity with an activation energy of 0.72 electron volts was found in one film at temperatures above 600°C. At this temperature the Hall effect drops sharply to zero, and the mobility varies as $\sim T^{-\frac{1}{2}}$ in this temperature range. The magnetoresistance effect of these films was found to be much smaller than that of bulk germanium. At liquid nitrogen temperature, a change in resistance of only 0.01 percent was detectable using a field of 6700 gauss.

* This work was supported by Signal Corps contract.

P3. Infrared Absorption in p-Type Germanium.* W. Kaiser, R. J. Collins, and H. Y. Fan, *Purdue University.*—The absorption in p-type germanium after subtracting the lattice bands does not show the same wavelength dependence as in n-type. At room temperature there are two weak absorption peaks[1] at 2200 cm^{-1} and 3500 cm^{-1} and a sharp rise[2] at 1800 cm^{-1} to a high absorption which remains constant out to 310 cm^{-1}. The absorption is on the average an order of magnitude higher than that in n-type samples of comparable carrier concentration. Results for samples between 0.07 and 0.85 ohm-cm can be normalized to a single curve. The absorption is approximately proportional to the carrier concentration. At 77°K, instead of the two bands at 2200 cm^{-1} and 3500 cm^{-1}, one sharp band with a peak at 2700 cm^{-1} was observed. The absorption at the peak is comparable with the two peaks observed at room temperature but falls to negligible values on either side. After the steep rise at 1800 cm^{-1} the absorption exceeds the room temperature curve and reaches a maximum between 400 cm^{-1} and 330 cm^{-1}. These observations suggest an overlapping of bands within the valence band.

* Work supported by Signal Corps.
[1] H. B. Briggs and R. C. Fletcher, Phys. Rev. **87**, 1130 (1952).
[2] R. J. Collins and H. Y. Fan, Purdue Semiconductor Research Progress Report, June 30, 1952.

P4. Infrared Absorption in n-Type Germanium.* R. J. Collins and H. Y. Fan, *Purdue University.*—Infrared absorption in n-type germanium has been investigated in the region 2 to 110 microns.[1] After subtracting the lattice bands[2] the absorption obtained increases with wavelength approximately as λ^2. For samples ranging from 0.006 to 0.1 ohm-cm, the absorption seems to be proportional to the carrier concentration rather than to the ratio of carrier concentration to mobility as predicted by theory. The magnitude of absorption coefficient is two orders of magnitude higher than that given by theoretical calculation. For the temperature range where the carrier concentration remains essentially constant the absorption seems to vary as the reciprocal of the mobility. For the intrinsic range the shape of the absorption *vs* wavelength curve is qualitatively a superposition of n-type and p-type curves as expected. The data taken at different temperatures can be normalized to a single curve. The semilog plot of the normalization factor against $1/T$ has a slope corresponding to a 0.71-ev energy gap.

* Work supported by Signal Corps.
[1] Measurements beyond 40 microns were made with the facilities at the University of Michigan through the courtesy of Dr. G. B. B. M. Sutherland.
[2] R. J. Collins and H. Y. Fan, Phys. Rev. **86**, 648 (1952).

P5. Photoconductivity and Carrier Traps in Germanium.* H. A. Gebbie, M. Nisenoff, and H. Y. Fan, *Purdue University.*—Photoconductivity in germanium has a maximum near the absorption edge. At room temperature results on both n- and p-type samples can be explained simply by excitation, recombination, and motion of electrons and holes. Good agreement is found for the values of minority carrier lifetime deduced from the variation of photoresponse with applied field and distance of illuminated area from electrodes, as well as from the time constant of rise and decay. For different samples the response is proportional to the lifetime. At 77°K the response can be divided into a fast and a slow component. The former varies linearly with radiation intensity, being faster and correspondingly smaller than the room temperature effect. This means a smaller lifetime at the lower temperature. The slow component saturates with increasing radiation intensity (I) according to $I/(I+\text{const})$. The rise becomes faster with increasing intensity while the decay remains unchanged. These observations show the presence of traps for excited minority carriers, the concentration and energy levels of which have been determined. Normal electron-hole recombination cannot however be mainly determines by these traps.

* Work supported by Signal Corps contract.

P6. Dislocations in Low Angle Boundaries in Germanium Single Crystals. F. L. Vogel, W. G. Pfann, H. E. Corey, and E. E. Thomas, *Bell Telephone Laboratories.*—Convincing evidence that certain lineage boundaries in nearly perfect germanium single crystals consist of arrays of parallel edge dislocations has been obtained by microscopic and x-ray measurements. The boundaries are revealed by etching as a series of regularly-spaced conical pits when viewed in planes normal to the growth direction and are invisible when viewed in planes parallel to the growth direction. Precision x-ray measurements at individual boundaries show that such boundaries separate highly perfect regions differing in orientation by a rotation about the growth axis of the order of one minute. The measured pit-spacings agree well with the spacings D between dislocations calculated from the orientation differences θ on the basis of Burgers model[1] for a low angle boundary, in which $D=b/\theta$, where b is the lattice translation vector. These findings strongly suggest that the pits are sites of edge dislocations.

[1] J. M. Burgers, Proc. Phys. Soc. (London) **52**, 23 (1940).

P7. Theory of Thermoelectric Power in Semiconductors.* V. A. Johnson and K. Lark-Horovitz, *Purdue University.*—The thermoelectric power Q of a classical semiconductor is found by obtaining the Thomson coefficient from electric and thermal current densities and integrating the Thomson relation. For an energy independent mean free path, the result is

$$Q=-(2k/e)\tanh z+(1/eT)(\zeta+\tfrac{1}{2}E_G)-(E_G/2eT)\tanh z,$$

where $z=\zeta/(kT)+E_G/(2kT)+\frac{1}{2}\ln(cm_e^{\frac{1}{2}}/m_h^{\frac{1}{2}})$, ζ denotes the Fermil level, E_G the forbidden band width, c the ratio of electron to hole mobility, and m_e and m_h the electron and hole effective masses. This expression reduces to the special forms obtained earlier.[1] The maximum error introduced by an approximation used in integration appears in the intrinsic range and is given by $(3k/4e)\ln(m_h/m_e)$ about 10 microvolts/deg in germanium. Information about the temperature dependence of E_G is obtained by applying this equation to high temperature Q data. At low temperatures the theory must be modified to consider energy dependence of mean free path, sample degeneracy, and breakdown of the Boltzmann-Lorentz development of the scattering process. Theoretical results will be compared with measurements.[2]

* Supported by a Signal Corps contract.
[1] V. A. Johnson and K. Lark-Horovitz, Phys. Rev. **69**, 259 (1946).
[2] H. P. R. Frederikse, Phys. Rev. **86**, 674 (1952).

P8. Electrical Conduction and Thermoelectric Power in Thorium Oxide Crystals. O. A. WEINREICH AND W. E. DANFORTH, *Bartol Research Foundation.*—The conductivity and thermoelectric power of homogeneous crystalline specimens of thorium oxide are being measured in different gas atmospheres and in vacuum. Conduction in hydrogen is relatively stable and is accompanied by electrolytic discoloration. In oxygen, conductivity is higher, increases markedly with flow of current and is not accompanied by visible electrolytic deposits. In all cases where a change is made from an oxygen atmosphere to a non-oxygen atmosphere (or vacuum) the conductivity decreases. One, therefore, speculates that the material is a p-type conductor when in oxygen and in the temperature range concerned (700°–1000°C). This is corroborated by the polarity of the Seebeck effect. In vacuum at higher temperatures evidence points to n-type conduction. Data regarding the variation of thermoelectric power with temperature in an oxygen atmosphere yield energy-gap valves in fair agreement with those obtained from electrical conductivity. Using the simplest semiconductor theory with present data, the calculated density of impurity centers is unreasonably high. However, it is to be expected that, under the circumstances, the impurity density will vary with temperature. An attempt to take this into account mathematically is in progress.

P9. Thick $p-n$ Junctions in Germanium.* RALPH BRAY AND F. VAN DER MAESEN,† *Purdue University.*—In single crystal Ge samples, we have found $p-n$ barrier regions of such thickness (~0.05 cm) as to permit probe determination of the potential distribution at low reverse bias and operation of a rectifying point contact *inside the barrier*. From the potential distribution one may estimate the space charge in the barrier, its variation with reverse voltage, and consequently the capacitance. This capacitance and the barrier thickness are relatively insensitive to applied voltage for one such barrier. A new three-terminal device has been constructed involving the interaction of the biased $p-n$ junction and a separately biased, n-type rectifying point contact made *inside the* $p-n$ *barrier*. For instance, the point contact circuit may operate in a normal, low forward resistance state, or in a very high resistance state, depending on relative magnitudes of point contact forward voltage and reverse bias on $p-n$ junction. The switching from one stage to the other is accompanied by a negative resistance region. The critical switching voltages are dependent on the position of the point inside the barrier and on illumination.

* Work supported by Signal Corps contract.
† Present address: Phillips Research Laboratory, Eindhoven, Holland.

P10. On Noise in $p-n$ Junction Rectifiers and Transistors. I Theory. RICHARD L. PETRITZ, *U. S. Naval Ordnance Laboratory and Catholic University.*—The problem of the noise resulting from concentration fluctuations of the minority carrier in $p-n$ junction rectifiers and transistors, as formulated and solved with a lumped parameter approximation[1] has now been solved without this approximation. Our result for $G_p(\Delta I_{ss}^2)$ is

$$G_p(\Delta I_{ss}^2)=\frac{4kT|z|^2}{R_p}\left\{\frac{e^{-qV_0/kT}+(z+z^*)}{(z+z^*)(z+z^*+1)}+\frac{e^{qV_0/kT}}{F^{z+z^*}}\int_0^F\frac{y^{z+z^*-1}}{(1+y)}dy\right\},$$

where $F=[\exp(qV_0/kT)-1]$, $z=(1+i\omega\tau_p)^{\frac{1}{2}}$; other symbols are defined in reference 1. $G_n(\Delta I_{ss}^2)$ is of similar form. For $\omega\tau_p<1$ the expression simplifies, and the available noise power is $\geqslant kT$ for all bias values; clearing up an anomaly in our approximate solution (reference 1, Eq. 63). Further studies of the noise resulting from fluctuations in the local lattice temperature show that the parameter h, in Eqs. 6 and 8 of reference 2, is essentially an average diffusion length of the minority carriers.

[1] Richard L. Petritz, Proc. Inst. Radio Engrs. **40**, 1440 (1952).
[2] Richard L. Petritz, Phys. Rev. **87**, 535 (1952).

P11. On Noise in $p-n$ Junction Rectifiers. II Experiment. FRANCES L. LUMMIS AND RICHARD L. PETRITZ, *U. S. Naval Ordnance Laboratory.*—Measurements of the absolute magnitude and spectrum of noise in $p-n$ junction rectifiers were made over the frequency range 15 cps to 600 kcps with different values of reverse dc bias and load resistance (R_L). The spectrum of the noise power across R_L can be fitted by an equation of the form $G(e^2, R_L)=A/[1+(2\pi f\tau)^2]+B/f$. An attempt has been made to interpret these results in terms of the two mechanisms discussed in the above abstract. According to the theory, the electronic noise corresponds to the term $A/[1+(2\pi f\tau)^2]$ and the lattice temperature noise to the B/f term, the parameters A, B, and τ being evaluated by experiments not involving noise measurements (see abstract No. P11). We find that the theoretical expression for electronic noise is in reasonably good agreement with the $A/[1+(2\pi f\tau)^2]$ term, both in regard to absolute magnitude and spectrum over the range of bias and R_L values used. However, the theoretical expression for lattice noise, whole adequately fitting a $1/f$ law, over the range of frequencies investigated, is not of sufficient magnitude to account for the experimental data.

FRIDAY EVENING AT 7:00

Main Dining Hall, Duke Union

(G. B. PEGRAM presiding)

Banquet of the Americal Physical Society

After-dinner speakers: G. B. PEGRAM, P. M. GROSS, R. J. SEEGER, W. SHOCKLEY, and T. J. KILLIAN.

SATURDAY MORNING AT 10:00

Howell Hall

(HOWARD REISS presiding)

Division of Chemical Physics

Symposium on Nucleation Theory

Q1. Nucleation in Condensed Systems. DAVID TURNBULL, *General Electric Company.* (30 min.)

Q2. Nucleation of Solid-Solid Transitions. JOHN HOBSTETTER, *Bell Telephone Laboratories.* (30 min.)

Q3. Role of Nucleation-Theory in Crystal Growth. N. CABRERA, *University of Virginia.* (30 min.)

Q4. Time Lag in Spontaneous Nucleation Due to Non-Steady-State Effects. F. C. COLLINS, *Polytechnic Institute of Brooklyn.* (30 min.)

Division of High-Polymer Physics

Invited Paper

Q5. Statistical Mechanics of Polymer Chains in Solution. B. H. ZIMM, *General Electric Research Laboratory.* (30 min.)

SATURDAY MORNING AT 10:00

Bingham Hall

(V. A. JOHNSON presiding)

Strain and Stress; Theoretical Solid-State Physics

R1. The Strength of Solid Solution Alloys.—JOHN C. FISHER, *General Electric Company.*—Short range order in an alloy, by which is meant any short-range departure from randomness in the arrangement of atoms on lattice sites, must strengthen the alloy. The increment of strength due to short range order, or order-hardening as it will be called, results from the fact that the motion of a dislocation through such an ordered alloy changes the nearest-neighbor configuration of atoms across the slip plane, producing a more nearly random configuration of higher energy. If γ is the mean energy increase per square centimeter of interface produced by the passage of a single dislocation, and if b is the magnitude of the Burgers vector for the dislocation, the order-hardening is given by the expression $\tau_0 = \gamma/b$. For an interface with $\gamma \approx 20$ ergs/cm^2 the order-hardening is $\tau_0 \approx 10^9$ dynes/cm^2, or 15 000 psi.

R2. Strain and Crystallite Size in Experimental Iron Powders.* FRANK E. JAUMOT, JR., AND LEONARD MULDAWER, *Franklin Institute Laboratories.*—The strain and crystallite size present in an experimental iron powder produced by a carbonyl process (General Aniline and Film Company, designated P818) has been determined. Electron microscopic examination gave a mean particle diameter of about two microns. The method used to determine the strain and crystallite size has been described by Warren and Averbach.[1,2] Using a combination of Fe and Cu radiation, the shapes of five powder diffraction lines were obtained for the powder and for a well-annealed "standard." From a Fourier analysis of these lines, a line profile due only to strain and crystallite broadening was obtained. A curve of the Fourier coefficients of this line profile as a function of the order of the diffraction lines gave the crystallite size and strain directly.[2] The crystallite size given by the analysis was of the order of 120A, and the rms strain was computed to be approximately 10^{-3}. These values are in reasonable agreement with those found by Taylor[3] by a different method, for a similarly prepared powder.

* This work was supported in part by the U. S. Office of Naval Research.

[1] B. E. Warren and B. L. Averbach, J. Appl. Phys. **21**, 595 (1950).
[2] B. E. Warren and B. L. Averbach, J. Appl. Phys. **23**, 497 (1952).
[3] A. Taylor, Pittsburgh Conference on Diffraction, November 7, 1952.

R3. The Yield Point Strain. EDWARD W. HART, *General Electric Research Laboratory.*—The yield point phenomenon in metals has been ascribed[1] to the anchoring of dislocations by solute atoms. The yield stress is that stress which produces appreciable thermal nucleation of free moving segments of dislocations from the regions in which they are anchored. A Frank-Read source,[2] initially anchored, can be activated to produce a dislocation burst[3] even though its critical stress is greater than the applied stress, if the size of a critical nucleus is smaller than the length of the source. This latter condition is readily verified by use of a simplified model for anchoring, suggested by J. C. Fisher.[4] This process provides a basis for explanation of the size of the yield point strain, the apparently homogeneous nature of much of the yield strain, the subsequent initial increase in hardening rate, and dependence of the strain on crystal size.

[1] A. H. Cottrell, Rep. Conf. on Strength of Solids, Phys Soc. London (1948).
[2] F. C. Frank and W. T. Read, Phys. Rev. **79**, 722 (1950).
[3] Fisher, Hart, and Pry, Phys. Rev. **87**, 958 (1952).
[4] Private communication.

R4. Change of Elastic Constants Resulting from Annealing of Cu and Al Cold Worked at −196°C.* E. C. CRITTENDEN, JR., AND H. DIECKAMP, *North American Aviation, Inc.*—The behavior of elastic constants after cold work or radiation

damage offers considerable promise as a tool for the identification of interstitial atoms in the presence of other imperfections. Interstitial atoms will probably increase the elastic moduli,[1] whereas vacancies and internal strain decrease the moduli. Preliminary observations have been made on Cu and Al wires treated so as to have a [111] fiber texture with the [111] fiber axis parallel to the wire axis. Since the shear modulus is isotropic for all directions in the (111) plane for cubic crystals, the modulus measured by torsion of such wires is a single crystal property. Such wires, 10 to 20 mils in diameter, were cold worked by twisting at −196°C to a surface strain of 0.5 and were then annealed by a series of 15-minute annealing pulses with a temperature increase of 25°C for each step up to room temperatures. All observations were made at −196°C between annealing pulses. The shear modulus can be observed to better than 5 parts in 10^4. The behavior of Cu and Al is very similar. After cold work the shear modulus had decreased about 10 percent. On annealing, the modulus recovered steadily throughout the range of −196°C to room temperature except in the region of −125°C for Al and −75°C for Cu where the modulus showed a slight decrease. This decrease suggests the loss of interstitial atoms during annealing.

* This report is based on studies conducted for the U. S. Atomic Energy Commission under contract AT-11-1-GEN-8.
[1] G. J. Dienes, Phys. Rev. **87**, 666 (1952).

R5. Theory of Initial Stress Strain Curves in Face-Centered Metals. J. S. KOEHLER, *University of Illinois.**—In an earlier paper[1] work-hardening by two mechanisms were considered: first, at small strains source hardening occurs, i.e., the longest free lengths of a dislocation generate and produce glide until they are locked by some process not yet understood. The hardening occurs because as the long dislocations are used more stress is required to make the short dislocations generate. At large strains the many dislocations present prevent additional dislocation motion; this is called interaction hardening. The temperature dependence of the source hardening in aluminum can be understood if it is assumed that all of the closely spaced glide lamellas found by electron microscopy in one slip band result from one source. The number of lamellas per band increases with increasing temperature. T. H. Blewitt[2] has found that source hardening in copper is the same at room temperature as it is at liquid nitrogen. This is consistent with C. S. Barrett's[3] observation that there exists only one glide lamella per slip band in copper at room temperature. The theory suggests that a search be made for multiple lamellas and stress strain curves dependent on temperature in copper crystals at elevated temperatures.

* Supported by the U. S. Office of Naval Research.
[1] J. S. Koehler, Phys. Rev. **86**, 52 (1952).
[2] T. H. Blewitt, see abstract this meeting.
[3] C. S. Barrett, Trans. Am. Inst. Mining Engrs. **156**, 62 (1944).

R6. X-Ray Measurements of Cold-Worked Alpha-Brass.* B. E. WARREN, B. L. AVERBACH, AND E. WAREKOIS, *M.I.T.*—Filings of 70–30 brass pressed into a briquet served as the cold-worked sample. Peak shapes were measured with a recording spectrometer using filtered CoKα. Fourier coefficients were determined and instrumental broadening corrected by the Stokes method. A log plot of the coefficients for the 111, 222 and the 200, 400 combinations gave particle sizes $L_{111}=180$A, $L_{100}=70$A, and slopes indicating appreciable distortion. Strip rolled to 98 percent reduction was used to get a strong (111) orientation and coefficients for (111), (222), (333) determined. The (333) points were above the (111), (222) line on the log plot indicating that an appreciable part of the particle size broadening is due to stacking faults. A small decrease in the (111), (200) peak separation and an increase in the (222), (400) separation was observed in agreement with Paterson's prediction for the effect of stacking faults. The distortion corresponds to a rms strain of 0.007. The results indicate that the x-ray broadening is due partly to distortion and partly to particle size, and that the particle size effect is largely due to stacking faults on the (111) planes at about every 25th plane.

* Sponsored by the U. S. Atomic Energy Commission.

R7. Comparison of Resistivity and Density Changes in Cold-Worked Brass. HERBERT I. FUSFELD, *Frankford Arsenal and Office of Ordnance Research.*—Experimental results have been obtained on the changes in resistivity of cold-worked brass with recovery at various annealing temperatures. All anneals were conducted below the recrystallization point. The curve shows certain maxima and minima. It is observed that the curve is similar to results obtained elsewhere on the changes in density of cold-worked brass as a function of annealing temperature. One curve may be transformed to the other by assuming that the underlying processes are identical, and are governed by an activation energy of approximately 19 000 calories per mole.

R8. Plastic Behavior of Polycrystalline Metals at Very High Strain Rates (~10^4/sec). L. ZERNOW AND J. SIMON, *Aberdeen Proving Ground.*—The behavior of a variety of polycrystalline metals at strain rates of the order of 10^4/sec is being studied. These strain rates are achieved by the explosive collapse of the metal into a high velocity jet[1–4] along which a velocity gradient exists. Observation of the behavior of the metal under these conditions is accomplished by means of fractional microsecond flash radiography.[3,4] The face-centered cubic metals, copper, nickel, aluminum, and silver, have been found to deform plastically quite readily with relatively small differences in their comparative behavior. Body-centered cubic materials like iron have been observed to undergo early fracture, as have also, members of the close packed hexagonal family cobalt and zinc. These results are consistent with and constitute an extension of the observations of Kramer and Maddin[5] on single crystals of α-brass, aluminum, and β-brass. Factors modifying the normal behavior will be discussed.

[1] Birkhoff, MacDougal, Pugh, and Taylor, J. Appl. Phys. **19**, 563 (1948).
[2] Pugh, Eichelberger, and Rostocker, J. Appl. Phys. **23**, 532 (1952).
[3] J. C. Clark, Phys. Rev. **72**, 741 (1947).
[4] L. Zernow, Bull. Am. Phys. Soc. **27**, No. 6, 10 (1952).
[5] I. R. Kramer and R. Maddin, J. Metals **4**, 197 (1952).

R9. Lattice Vibrations in Graphite. HERBERT B. ROSENSTOCK, *U. S. Naval Research Laboratory.*—Gurney[1] justifies the assumption that, at low temperatures, the only vibrations that are excited in the graphite lattice are transverse ones propagated in the principal hexagonal crystal planes. On this assumption, the frequency distribution may be calculated exactly[2,3] for certain values of the force constants α, β, γ, for nearest, 2nd-nearest, and 3rd-nearest neighbors. The specific heat calculated from these "exact" distributions is slightly sensitive to the choice of β/α and γ/α, differing somewhat from the T^2 law predicted by Debye theory throughout the temperature range of interest here. Comparison with experiment[4] yields a numerical value for the parameter $\theta=\hbar\omega_{\max}/zk$, and from this the values of the force constants, which are related to $\omega_{\max}$, may be inferred. Numerical results will be given.

[1] R. W. GURNEY, Phys. Rev. **88**, 465 (1952).
[2] E. W. Montroll, J. Chem. Phys. **15**, 575 (1947).
[3] W. A. Bowers and H. B. Rosenstock, J. Chem. Phys. **18**, 1056 (1950).
[4] Esterman and Kirkland, as quoted in reference 1.

R10. Plasma Waves in Metals. P. A. WOLFF, *Bell Telephone Laboratories.*—The Hartree approximation is used to investigate the effect of the crystal lattice on plasma oscillations in metals. The plasma frequency is given by the formula $\omega^2=4\pi e^2 n_0\langle 1/m_s^*\rangle$, where n_0 is electron density and $\langle 1/m_s^*\rangle$ the average of the effective mass over filled states. For free electrons this equation reduces to that given by Bohm and Gross:[1] for insulators $\langle 1/m_s^*\rangle=0$ and there are no oscillations.

Interband transitions induced by the plasma waves cause frequency broadening and probably are responsible for the large widths observed in Cu, Ni, and Ag.[2] The matrix element for such a transition is the same as for optical absorption; *d*-electrons, being more numerous and more tightly bound contribute the major share of the transition probability.[3] This explains why plasma lines observed in Be and Al are much narrower than those seen in the metals mentioned above. A rough estimate of the frequency shift due to interband transitions is made and shown to be consistent with experiment.

[1] Bohm and Gross, Phys. Rev. **75**, 1851 (1949).
[2] G. Ruthemann, Ann. Physik **2**, 113 (1948); W. Long, Optik **3**, 233 (1948).
[3] The suggestion that *d*-electrons are mainly responsible for the broadening was first made by Conyers Herring.

R11. A New Treatment of Energy Bands. NORMAN ROSTOKER AND WALTER KOHN, *Carnegie Institute of Technology.*—The problem of finding the propagating electron wave functions of a crystal can be formulated as an integral equation, which leads to a stationary expression for the energy. If one employs only trial functions which satisfy the Schrödinger equation, the potential can be eliminated from this expression. The resulting secular equation depends only on the Green's function for the lattice under consideration and the logarithmic derivatives of the $s, p, d, \cdots$ etc., radial functions at the inscribed sphere of the atomic polyhedron. The Green's function is completely determined by the geometry of the crystal lattice while the logarithmic derivatives are determined by the ionic potential. Therefore, in this treatment, the effects of the type of lattice and of the ionic potential on the structure of the energy bands are clearly separated. The methods goes beyond the spherical approximation and takes into account the detailed shape of the atomic polyhedron. Preliminary results for lithium will be presented. We plan to apply this method next to transition metals.

R12. Brillouin Zone Structures of Alloys. Part I. Some Implications of Present Theories. E. I. SALKOVITZ AND A. I. SCHINDLER.—The changes occurring in the lattice parameters a and c and their ratio c/a in dilute magnesium solid solutions have been carefully studied by Hume-Rothery and Raynor[1] and others. The changes in the c/a ratio of these solutions have been interpreted by H. Jones[2] to be associated with a change in the Fermi energy arising from the distortion of the Brillouin zone: that is, these c/a changes are associated with an overlap which takes place at a given electron to atom ratio. This interpretation implies that an anomaly should exist in the conductivity *versus* concentration curve for these alloys. An indirect consequence should be the breakdown of Linde's and Matthiessin's rules. Indeed Linde's rule may be expected to be invalid on other grounds. The rule was based on dilute alpha-solutions of monovalent metals and has not been thoroughly checked for bivalent metals. It will be necessary to establish the dependence of the scattering probability upon alloying addition when c/a varies. These considerations also raise doubt concerning the validity of Matthiessin's rule.

[1] W. Hume-Rothery and G. V. Raynor, Proc. Roy. Soc. (London) **177**, 27 (1940); G. V. Raynor, *ibid.* **180**, 107 (1942); and R. S. Busk, Trans. Am. Inst. Mining Met. Engrs. **188**, 1460 (1950).
[2] H. Jones, Proc. Roy. Soc. (London) **A147**, 400 (1934); Physica **15**, 13 (1949); Phil. Mag. **41**, 663 (1950).

R13. Brillouin Zone Structures of Alloys. Part II. Hall Constant Data of Dilute Magnesium Alloys. A. I. SCHINDLER AND E. I. SALKOVITZ.—To explain the peculiar variation of the lattice parameters of dilute alpha-solutions of magnesium, H. Jones has postulated a Brillouin zone overlap at a certain electron to atom ratio. A direct consequence of this theory is that a significant effect should be found on the Hall constant when overlap occurs. In the application of the Jones' theory, other writers have tacitly assumed that the metals in column I of the periodic table have one valence electron, those in column II have 2, and those in column III, three electrons per atom. However, it is generally accepted that the valence of the solute is not necessarily equal to the number of outer electrons. An insight into the contribution of electrons to magnesium by the solute can be obtained from Hall data. If overlap occurs, the variation of Hall constant with solute concentration should be abrupt at overlap. As a test of these ideas, Hall data, using a technique described by Schindler and Pugh,[1] were obtained at room temperature on magnesium containing 0.8, 1.3 and 1.8 atomic percent aluminum and 0.1, 0.2, and 0.3 atomic percent silver. In both cases, the Hall constant decreased rapidly as a function of solute concentration with the variation in the silver approximately three times that of the variation in aluminum. These results will be discussed and an experimental program outlined.

[1] A. I. Schindler and E. M. Pugh, Phys. Rev. **89**, 295 (1953).

SATURDAY MORNING AT 10:00

Venable Hall

(NELSON FUSON presiding)

Infrared Spectroscopy

S1. A New Detector for the Infrared. S. MROZOWSKI, B. D. MCMICHAEL,* AND E. A. KMETKO, *University of Buffalo.*—In the process of condensation of aromatic molecules into large graphite planes, the energy gap between the filled and empty bands gradually decreases to zero, and the corresponding long-wave absorption edge moves from the visible into the infrared. By stopping the condensation process at a definite stage, substances with energy gaps as narrow as required can be produced. In this work the photoresponse of films made by heat-treating cellophane was investigated. A remarkable bolometric effect was found and also the presence of an internal photoeffect established. In general, the films with the best photoeffect showed a signal-to-noise ratio inferior to the PbS cells (by a factor of about 20 at 200 cycles.) However, the frequency response is good (checked only up to 2000 cycles), the maximum of sensitivity seems to be located in the infrared, and the long-wave limit coincides roughly with the absorption edge. By interposing another film with a shorter wavelength, absorption limit cells responding to a specified spectral region can be built. Cells with a sensitivity limit only up to about 5μ were obtained; the increasing conductivity of the films preventing a further extension into the infrared.

* Now at the Bell Aircraft Corporation, Niagara Falls, New York.

S2. An Infrared Analysis of the Associated O—H and O—D Stretching Vibrations of Simple Carboxylic Acids.* NELSON FUSON, MARIE-LOUISE JOSIEN, AND CONRADE C.

HINDS, *Fisk University.*—This paper reports a study of the "fine structure" of the associated hydroxyl group stretching vibration band of carboxylic acids, using a single beam infrared spectrometer equipped with a lithium fluoride prism. The compounds, studied in the vapor and/or solution state, included CF_3COOH, CF_3COOD, and CH_3COOD. Previously reported experimental results and interpretations[1] will be discussed in relation to the present findings, and a new explanation for the "fine structure" will be proposed.[2]

* This investigation has been supported by a Frederick Gardner Cottrell grant from the Research Corporation.
[1] V. M. Chulanovskii and P. D. Simova, Doklady Akad. Nauk. S.S.S.R. **68**, 1033 (1949); D. Hadzi and N. Sheppard, Boll. sci. facoltà chim. ind. univ. Bologna **10**, 25 (1952); M. Davies and J. C. Evans, J. Chem Phys. **20**, 342 (1952); and Fuson, Josien, Jones, and Lawson, J. Chem. Phys. **20**, 1627 (1952).
[2] M.-L. Josien and N. Fuson, Compt. rend. **235**, 1025 (1952).

S3. An Infrared Study of the Influence of Molecular Structure on the Carbonyl Band in Polycyclic Quinones.* MARIE-LOUISE JOSIEN, NELSON FUSON, AND ESSIE M. SHELTON, *Fisk University.*—A study of the position of the infrared absorption associated with the carbonyl bond vibration in over one hundred quinones[1-3] leads to some interesting correlations between the C=O frequency and other measures of molecular structure such as oxidation-reduction potential, bond order, index of free valence, Hammett's function, and the geometrical form of the molecule. Certain hydroxy-substituted quinones show spectral anomalies which do not seem to fit into the usual category of hydrogen bonded compounds.

* This investigation was supported by a research grant from the National Cancer Institute, United States Public Health Service.
[1] M.-L. Josien and N. Fuson, Bull. soc. chim. France **19**, 389 (1952).
[2] Josien, Fuson, Lebas, and Gregory, J. Chem. Phys. **21**, 331 (1953).
[3] Josien, Fuson, and Pearson, Compt. rend. **235**, 1206 (1952).

S4. The Infrared Spectrum and Molecular Constants of Deuterium Bromide. F. L. KELLER AND A. H. NIELSEN, *University of Tennessee.*—High dispersion measurements have been made for the first time on the fundamental ($v=0\rightarrow1$), first overtone ($v=0\rightarrow2$), and second overtone ($v=0\rightarrow3$) infrared vibration bands of DBr. The fundamental was observed by using a 40-cm cell and pressures of 90–150 mm. The overtones required the use of a multiple reflection cell with a path of 17 meters and pressures of 240–460 mm. It was necessary to elminate strong atmospheric absorption in the region of each band. The isotopic splitting of the rotation lines was measured and molecular constants determined for both isotopic species, DBr^{79} and DBr^{81}. The principal constants for DBr^{79} are $\omega_e=1885.33$ cm^{-1}, $x_e\omega_e=22.73$ cm^{-1}, $y_e\omega_e=-0.0106$ cm^{-1}, $B_e=4.290_8$ cm^{-1}, $\alpha_e=0.083_9$ cm^{-1}, $D_e=0.000096_4$ cm^{-1}, $\beta=-2_2\times10^{-6}$ cm^{-1}. The principal constants for DBr^{81} are $\omega_e=1884.75$ cm^{-1}, $x_e\omega_e=22.72$ cm^{-1}, $y_e\omega_e=-0.0106$ cm^{-1}, $B_e=4.287_6$ cm^{-1}, $\alpha_e=0.083_3$ cm^{-1}, $D_e=0.000095_9$ cm^{-1}, $\beta=-2_2\times10^{-6}$ cm^{-1}. These values are in good agreement with constants obtained from recent measurements on the fundamental vibration of HBr by Thompson, Williams, and Callomon.[1]

[1] Thompson, Williams, and Callomon, at the Physical Chemistry Laboratory, Oxford (private communication).

S5. A Study of the Infrared Spectrum of the Amide Group. HARRY LETAW, JR.,* AND ARMIN H. GROPP, *University of Florida.*—Two assignments have been proposed for the very strong 1560 cm^{-1} band of the N-substituted amide group. Lenormant[1] has suggested its assignment to ν(C–N) and Richards and Thompson[2] have suggested δ(N–H). This investigation consisted of a study of the frequency shifts of this and other bands in the infrared spectra of several *n*-butyl- and N,N-dibutyl-ethanamides upon substitution of chlorine and fluorine in the 2-position. On the basis of these shifts and other properties of the band in question, observed in the spectra both of the pure compounds and of their CCl_4 solutions, it is concluded that the ν(C–N) assignment is correct. The apparent absence of the corresponding band from the spectrum of the N,N-disubstituted amide group is explained by the accidental degeneracy of ν(C=O) and ν(C–N).

* U. S. Atomic Energy Commission, Predoctoral Fellow. Now at the University of Illinois.
[1] H. Lenormant, Ann. chim. **5**, 459 (1950).
[2] R. E. Richards and H. W. Thompson, J. Chem. Soc. (London) 1248 (1947).

S6. The Infrared Absorption Spectrum of SO_2.* R. D. SHELTON, A. H. NIELSEN, AND W. H. FLETCHER, *University of Tennessee.*—The infrared absorption spectrum of SO_2 was recorded with a grating spectrometer from 470 cm^{-1} to 8000 cm^{-1} with path lengths up to 20 atmometers. Fifteen bands were observed. Band centers of ν_2, ν_1, ν_3, $\nu_2+\nu_3$, $2\nu_1$, $\nu_1+\nu_3$, $2\nu_3$, $2\nu_1+\nu_2$, $\nu_1+\nu_2+\nu_3$, $3\nu_1$, $2\nu_1+\nu_3$, $3\nu_3$, $3\nu_1+\nu_3$, and $\nu_1+3\nu_3$ have been assigned frequencies of 517.76, 1151.30, 1361.11, 1875.58, 2295.82, 2499.55, 2715.30, 2815.98, 3011.25, 3431.19, 3629.57, 4054.26, 4751.23, and 5165.64 cm^{-1}, respectively. The first five had been previously observed.[1] Combination relations based on a symmetric top approximation were applied to the Q branches of the a_1 type bands ν_1, ν_2, $2\nu_1$ and $2\nu_3$. These gave respective (A″−B″) values of 1.7009, 1.6903, 1.7144, and 1.7044 cm^{-1}, and respective $(A'-B'-A''+B'')$ values of −0.00035, +0.0370, −0.0538, and −0.0367 cm^{-1}. Combination relations applied to ν_3 gave $B''=0.3023$ cm^{-1} and $(B'-B'')=-0.00010$ cm^{-1}. Using the B'' value from ν_3 and the average $A''-B''$ from above, $A''=2.0048$ cm^{-1} compared with $A''=2.0271$ cm^{-1} from microwave data.[2] Calculation of the harmonic and anharmonic constants gave $\omega_1^0=1155.62$, $\omega_3^0=1368.06$, $x_{11}=-3.95$, $x_{33}=-5.52$, $x_{13}=+1.20$, $x_{23}=-3.59$, $x_{13}=-13.52$.

* Supported by the U. S. Office of Ordnance Research.
[1] G. Herzberg, *Infrared and Raman Spectra of Polyatomic Molecules* (D. Van Nostrand Company, Inc., New York, 1945), p. 285.
[2] M. H. Sirvetz, J. Chem. Phys. **19**, 938 (1951).

S7. Infrared Grating Spectrum of CH_3CN Vapor. F. W. PARKER, A. H. NIELSEN, AND W. H. FLETCHER, *University of Tennessee.*—Although the microwave spectrum[1] and infrared prism spectrum[2] of CH_3CN have been investigated, high dispersion infrared measurements have not been reported, and spectral regions masked by atmospheric H_2O vapor and CO_2 have been inadequately studied. Using a prism-grating spectrograph and suitable absorbants for H_2O and CO_2, it has been possible to measure many bands under high resolution from 1.5–16 mu. The parallel band $\nu_4(a_1)$ at 920 cm^{-1} and perpendicular bands $\nu_7(e)$ and $\nu_5(e)$ at 1050 cm^{-1} and 3010 cm^{-1} have been well resolved, and partial resolution of the P and R branches of $2\nu_8(A_1)$ at 715 cm^{-1} has been achieved. A multiple reflection cell with path length of 20 meters was used with vapor pressures as high as 60 mm in a search for combination and overtone bands. Resolution of bands at 2100, 4000, 4400, and 5600–6100 cm^{-1} resulted. New bands have been found at 1800, 4160–4210, 4840, 5014, 5270, 5410, 5845, 5965, and 6135 cm^{-1}, some of which exhibit rotational structure.

[1] H. H. Nielsen, Phys. Rev. **77**, p. 130 (1950); Kessler, Ring, Trambarulo, and Gordy, Phys. Rev. **79**, 54 (1950).
[2] P. Venkateswarlu, J. Chem. Phys. **19**, p. 293 (1951).

S8. An Analysis of the Infrared Spectrum of CF_3COCl. ROBERT JAMES LOVELL, *Vanderbilt University.*—The spectrum of CF_3COCl has been recorded in the rocksalt region from two to fifteen microns. Eighteen bands were observed, of which six are thought to be fundamentals and twelve overtones and combinations. The molecule has at most one plane of symmetry, and, therefore, has been assigned to the C_s point

group. Of the fifteen possible fundamentals, ten are A' (vibrations parallel to the plane of symmetry) and five are A'' (vibrations perpendicular to the plane of symmetry). The selection rules for this group allow all vibrations (both fundamentals and overtones and combinations) to appear in the infrared region. Utilizing data from studies (made by the author) of the Raman and infrared spectra of the analog CF_3COBr and a knowledge of the characteristic group frequencies involved, an attempt is made to follow Morris[1] and Wilson and Wells[2] in assignment of the fundamentals and overtones and combinations present in the infrared spectrum of CF_3COCl.

[1] J. C. Morris, J. Chem. Phys. **11**, 230 (1943).
[2] E. B. Wilson, Jr., and A. J. Wells, J. Chem. Phys. **9**, 319 (1941).

S9. Raman Spectrum, Force Constants, and Calculated Thermodynamic Properties of Germanium Tetrafluoride. LAWRENCE K. AKERS AND ERNEST A. JONES, *Vanderbilt University.*—One fundamental frequency of the Raman spectrum of gaseous GeF_4, the symmetrical frequency ν_1, has been obtained. Using this and other previously reported fundamentals,[1] force constants using various potential functions have been calculated. The thermodynamic properties, heat content, free energy, heat capacity, and entropy have also been calculated using spectroscopic data and the usual harmonic oscillator, rigid rotator approximation. Calculations are for ideal gas at one atmosphere pressure for temperatures 100°–1000°K.

[1] P. G. H. Woltz and A. H. Nielsen, J. Chem. Phys. **20**, 307 (1952).

SATURDAY MORNING AT 10:00

Phillips Hall

(A. M. WEINBERG presiding)

Effects of Irradiation on Solids

T1. Additional Data on the Resistivity of Cu_3Au during Neutron Irradiation. HARVEY L. GLICK AND W. F. WITZIG, *Westinghouse Electric Corporation.*—A continuation has been made of work[1] dealing with neutron irradiation of Cu_3Au at 80°C±7C° within a graphite moderated nuclear reactor. The initially ordered specimen resistivity continued to increase to a value 60 percent above its initial value at 2×10^{20} neutrons/cm². The initially disordered specimen resistivity reached a minimum 7.5 percent below its initial value at 5×10^{19} nvt and increased thereafter to a value 4.2 percent below its initial value. A disordered specimen held at 80°C without neutron irradiation showed that the above effect was not produced by temperature alone. Similar specimens were irradiated at 140°C±10C°. At 4×10^{18} nvt, the resistivity of the initially ordered specimen dropped 6 percent, then increased slowly to a value 4 percent above its initial value at 1.4×10^{20} nvt. The resistivity of the initially disordered specimen dropped 12 percent in 4×10^{18} nvt, another 5 percent at 2.5×10^{19} nvt and then remained substantially constant. A disordered specimen held at 140°C without neutron irradiation suffered a resistivity drop of 4 percent in a day and then remained essentially constant. These results indicate that the effect of irradiation is dependent upon the temperature of the specimen.

[1] Glick, Brooks, Witzig, and Johnson, Phys. Rev. **87**, 1074 (1952).

T2. X-Ray and Metallurgical Studies on Neutron Irradiated Cu_3Au. R. H. FILLNOW, E. K. HALTEMAN, AND G. F. MECHLIN, *Westinghouse Electric Corporation.*—Metallurgical and x-ray diffraction studies have been made on samples of Cu_3Au irradiated as a part of the 80°C electrical resistivity experiment discussed in the previous paper. Vickers hardness has been determined on sets of disordered and ordered material both before and after irradiation. The hardness of the disordered material increased by 21 vhn from an initial value of 100 vhn after an exposure of 3×10^{20} nvt. The ordered material increased by 48 vhn from an initial value of 110 vhn for the same exposure. Photographs of microstructure have been made and will be discussed. X-ray diffraction patterns have been obtained from powdered material having simultaneously received the heat treatment given the electrical resistivity and metallurgical samples. Debye-Scherrer patterns were made in a 114-mm camera on extruded samples with a starch diluent. Visual examination of the pattern indicates essentially no change in the disordered material and a perceptible sharpening after irradiation on the ordered material. Studies of the long range order parameter indicate only a small decrease in long range order. Lattice parameter determinations show no significant alteration of parameter for the disordered material but a significant increase in parameter for the ordered material.

T3. The Effect of Fast Neutron Bombardment on Diffusion in Cu_3Au. R. R. COLTMAN AND T. H. BLEWITT, *Oak Ridge National Laboratory.*—Previous work has indicated that fast neutron irradiation increases the rate of ordering of Cu_3Au. Prior to neutron bombardment two Cu_3Au resistors with a degree of order corresponding to equilibrium at 376°C were annealed at 150°C for 100 hours without appreciably affecting the resistance. The samples were then irradiated in the ORNL graphite reactor at 150°C. One sample was exposed to a fast neutron flux of 1×10^{12} neutrons/cm² and the other to 2.5×10^{11} neutrons/cm²/sec. The resistance of the sample exposed to the lower flux approached a minimum approximately 25 percent lower than the original value with about half of the decrease occurring in the first 24 hours. The other sample behaved similarly, however, approached the minimum four times as fast. A third specimen was bombarded for one week at −160°C in a flux of 2×10^{10} neutrons/cm²/sec. At this temperature the sample apparently disordered as a small increase (0.6 percent) was observed. Subsequent annealing for 3.5 hours at −80°C produced no change in resistance. Annealing at 0°C, 100°C, and 150°C indicated a relaxation time of approximately 50 hours at 0°C, 25 minutes at 100°C, and 10 minutes at 150°C. A total decrease in resistance of 4.7 percent was observed.

T4. The Deformation of Copper Crystals at 78°K and 300°K. T. H. BLEWITT, J. K. REDMAN, AND F. A. SHERRILL, *Oak Ridge National Laboratory.*—Experiments were designed to study the phenomena of low temperature recovery of the electrical resistance in copper single crystals. Pairs of crystals were simultaneously grown by the Bridgman technique with identical orientation. One sample of each pair was deformed at 300°K and the other at 78°K. The data obtained from four pairs of crystals indicate that: 1. The critical shear stress is independent of temperature. 2. The rate of work hardening is

temperature independent for shear strains less than 0.20. For shear strains greater than this the rate of work hardening for samples deformed at 78°K is about twice that of their corresponding sample at 300°K. 3. No recovery of the electrical resistance (±0.1 percent) was observed for a 16-hour anneal at 300°K when the shear strain was less than 0.20. For shear strains greater than 0.20, however, a recovery occurs whose magnitude depends on the strain in excess of 0.20. 4. There is no apparent recovery of the hardness associated with the recovery of resistance, however, a definite yielding phenomena is observed. It would appear possible that one variety of defect capable of moving at 300°K to form Cottrell atmospheres is formed by sufficiently large deformations.

T5. Some Deformation Characteristics of Reactor Irradiated Copper Single Crystals at 78°K and 300°K. R. E. JAMISON AND T. H. BLEWITT, *Oak Ridge National Laboratory.*—Characteristics thus far observed on extension of reactor irradiated pure copper single crystals appear to be strongly dependent on the deformation temperature. Pairs of samples of the same orientation and irradiation were extended, one at room temperature and the other at liquid nitrogen temperature. The critical shear stress is increased at the lower temperature while the initial rate of work-hardening is decreased in such a way that the stress-strain curve after a strain of about 0.20 is similar to the curve for unirradiated copper at 78°K. The room temperature curves are nearly coincident for the larger strains. Cross slip is not as distinct at 78°K, and the slip lines are more closely spaced and in smaller clusters than those formed at room temperature. At 78°K the irradiated crystals will sometimes break in brittle fracture, depending on the initial orientation. The brittle fractures are preceded by a series of audible clicks with accompanying releases of stress and formation of crevices in the crystal surface.

T6. Annealing of Bombardment Damage in Germanium: Theoretical. R. C. FLETCHER, W. L. BROWN, AND S. MACHLUP, *Bell Telephone Laboratories.*—On bombardment of germanium with electrons of more than 650 kev,[1] germanium atoms are displaced to interstitial positions. Part of the defects thus produced will anneal at room temperature, apparently monomolecularly.[1] The remainder can be annealed at higher temperatures, but this part of the annealing requires too great a range of time at a given temperature to be either monomolecular or bimolecular recombination. It is proposed that the complete annealing process can be divided into three stages. First, interstitials displaced only a short distance from their vacancies will recombine monomolecularly because of lattice distortion. Second, interstitials farther away from their vacancies will diffuse, some of them recombining but some escaping from the vicinity of their own vacancies. Third, interstitials which have escaped in the second stage will continue to diffuse and will eventually recombine bimolecularly with other vacancies than their own. Similar considerations apply if vacancies diffuse rather than interstitials. Calculation of the various stages of the annealing, including the appropriate temperature dependence, have been made for an isotropic medium and for a diamond-type lattice. These calculations show an annealing which covers the range of time observed.

[1] E. E. Klontz, Signal Corps Report, Purdue University, June, 1952.

T7. Annealing of Bombardment Damage in Germanium: Experimental. W. L. BROWN AND R. C. FLETCHER, *Bell Telephone Laboratories.*—The previous paper indicates that the annealing of bombardment-introduced defects in germanium above room temperature may be described by a simple diffusion theory. An interstitial atom moves in the crystal by jumping between nearest neighbor sites of the interstitial lattice. The mean jump time τ varies with temperature, T, according to $\tau = \nu_0^{-1} \exp E/kT$, where E is the energy hump between interstitial positions and ν_0 is approximately the lattice vibrational frequency. In the simple diffusion model, the extent of annealing depends only upon the total number of jump times no matter what the temperature. Five n-type samples with an initial room temperature conductivity about 1 mho/cm were given equal bombardments with 3-Mev electrons. Each sample was annealed at 100° temperature intervals for seventy minutes. The five were interlaced to cover the temperature range from 140 to 360°C in 20° intervals. The annealing curves at different temperatures can be made to overlap by adjustment of the time scales. On the resultant curve, the times corresponding to 10 percent and 90 percent of complete annealing are in the ratio of 10^5. From the factors arising in adjustment of the time scales, an activation energy of 1.8 ev is obtained.

T8. Effect of Neutron Irradiation on the Phase Change in Tin.* JEROME FLEEMAN, *Brookhaven National Laboratory.*—The β-phase of tin transforms into the α-phase at transition temperatures below −13°C. The rate of transformation is known to vary as a function of the temperature[1] having a maximum at roughly −30°C. We have initiated a study of the influence of irradiation on the transformation rate of this phase change. Annealed samples of tin 0.25 in.×0.75 in. and 20 mils thick have been exposed at and near liquid nitrogen temperatures in the Brookhaven pile for periods of one and two weeks. After removal from the pile they have been kept at liquid nitrogen temperature until the radioactivity has died down sufficiently to allow visual examination. These specimens have been compared with similar tin samples unirradiated. The latter show no evidence of transformation whereas the irradiated samples show evidence of the characteristic grey tin "pimple" indicating marked influence of the irradiation upon the transformation. Photographs of irradiated and unirradiated specimens will be shown.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] G. Tamman and K. L. Dreyer, Z. anorg. u. allgem. Chem. **199**, 97 (1931).

T9. Electron Mean Free Path of Damaged Copper in Terms of Electrical Resistivity and Thermoelectric Power.* G. W. RODEBACK AND W. P. EATHERLY, *North American Aviation, Inc.*—According to Sommerfeld's theory of metals, thermoelectric power involves the energy derivatives of the electron mean free paths of the two metals. Measurements of the thermoelectric power of an annealed—cold-worked copper thermocouple have been made from 4.2°K to 300°K, together with resistivity measurements over the same temperature range. From these data an attempt was made to determine the type of scattering introduced by the cold work. By Mathieson's rule the reciprocal mean free path of the cold-worked metal is the sum of the reciprocal mean free paths for the crystalline structure and for the cold-work damage. The former mean free path is assumed to vary with the square of the degeneracy energy while the latter is assumed to be independent of energy, representing the effect of isolated scattering centers. This plus the Sommerfeld expressions for resistivity and thermoelectric power result in the determination of the temperature and energy dependence of the mean free paths together with a relation for the energy which is independent of electron density or mass. The observed constancy within 3 percent of the energy (4.3 ev) and the fixed scattering term, from 120°K to 300°K, appears to verify the assumption of isolated scattering centers (for example, vacancies and/or interstitials).

* This report is based on studies conducted for the U. S. Atomic Energy Commission.

T10. Hardness Change in Cu Irradiated with 1.25-Mev Electrons.* C. E. DIXON AND C. J. MEECHAN, *North American Aviation, Inc.*—The primary effects of pile and cyclotron ir-

radiation in metals are[1] (1) the production of interstitials and vacancies and (2) the production of thermal spikes. The indentation hardness increases which have been observed as a result of such irradiations may be a consequence of (1) or (2) or both. It appears that thermal spike effects are negligible when the irradiation consists of 1-Mev electrons since no disordering was observed upon irradiating ordered Cu_3Au.[2] This result suggests the attractive possibility of using electron irradiation to isolate the effects of (1) from (2). A moderate electron bombardment (5×10^{18} electrons/cm^2) of annealed copper was carried out at about -20°C. Tukon hardness measurements made at room temperature showed a change in D.P.H. number from 44.3 to 47.7 kg/mm^2 between the non-irradiated and irradiated portions of the specimen, respectively. About half of this increase annealed out in 8 hours at 170°C. It is believed this indicates that either interstitials or vacancies can contribute to hardness changes.

* This report is based on studies conducted for the U. S. Atomic Energy Commission.

[1] F. Seitz, Phys. Today **5**, 6 (June, 1952).

[2] Dixon, Meechan, and Brinkman (to be published in Phil. Mag.).

T11. Displacement Energy for Radiation Damage in Copper. D. T. Eggen and M. J. Laubenstein, *North American Aviation.*—M. Mills[1] has proposed the measurement of the lattice displacement energy in crystals by electron bombardment. Following this theory, Klontz has measured the displacement energy in Ge to be about 30 ev[2] and Denney has measured that in a Cu-Fe alloy to be about 26.5 for the iron.[3] A target box was constructed so as to be an extension of the acceleration tube of the NAA statitron. Thin Cu specimens were mounted on a heavy copper plate which was immersed in liquid air during the irradiation and measurements. Electrical resistance measurements were made at various times during the irradiation. The rate of change of the resistance of the damaged sample was plotted for electron energies ranging from 0.45 to 1.0 Mev. These slopes were then plotted against the electron energy. The zero damage intercept occurs at an electron energy between 0.45 and 0.50 Mev (0.49 ± 0.02 Mev). This corresponds to a displacement energy in copper of about 25.0 ± 1.0 ev.

[1] M. M. Mills (personal communication).

[2] E. E. Klontz, Ph.D. thesis, Purdue University, June, 1952.

[3] J. Denney, Bull. Am. Phys. Soc. **27**, No. 6, 9 (1952).

T12. Low Temperature Fast Neutron Bombardment of Copper-Beryllium Alloy. J. W. Cleland, D. S. Billington, and J. H. Crawford, Jr., *Oak Ridge National Laboratory.*—Taylor and Murray[1] have investigated the behavior of electrical resistivity and hardness of a solution-quenched copper-beryllium alloy containing 2 percent Be under pile irradiation at ~300°K. They attribute the appreciable increase in hardness and resistivity to the formation of precipitate nuclei made possible by enhanced microdiffusion associated with radiation disordering. Such an enhancement has been demonstrated by Blewitt and Coltman[2] for the in-pile ordering of Cu_3Au. In order to check this proposed mechanism for copper-beryllium, solution-quenched samples have been irradiated consecutively at ~120°K and ~300°K. The increase in resistivity at 120°K for a given exposure in the graphite reactor is smaller by about a factor of four than that observed at 300°K. If a sample, bombarded for some period at ~120°K, is subsequently irradiated for a short period at or somewhat above 300°K, the total change in resistivity is approximately that which would be expected if the total irradiation were carried out at ~300°K. These results indicate that the greater portion of radiation induced resistance increase depends on a process, presumably microdiffusion, which involves thermal activation.

[1] W. E. Taylor and G. T. Murray, Oak Ridge National Laboratory Report No. ORNL 1323 (to be published in Acta Metallurgica).

[2] T. H. Blewitt and R. R. Coltman, Phys. Rev. **85**, 384 (1952).

T13. Nature of Radiation Damage in Diamond.* G. J. Dienes and D. A. Kleinman, *Brookhaven National Laboratory.*—Debye temperature measurements[1] on irradiated silicon indicate strongly that the damage in this crystal cannot be explained by the presence of vacancies and interstitials. A model of radiation damage, applicable to silicon and diamond, has been constructed to explain the above observation and stored energy and lattice parameter changes. The model is based on the known tendency of carbon and silicon to form structures with single and double bonds. Energetic recoil atoms rupture the covalent single bonds which then reform into a system of double and single bonds. Calculations on diamond, which successfully correlate stored energy and lattice expansion with radiation dosage indicate that: (a) each fast neutron collision produces an isolated disordered region, (b) these regions are about 45A in diameter and contain about 10^4 atoms, (c) these regions are mechanically weak due to the rupture of bonds and may be considered as holes in the diamond. The predicted decrease in the elastic constants of diamond is of the same order of magnitude as found experimentally for silicon. In this model 10–100 times more atoms are involved than in the vacancy-interstitial picture.

* Under contract with the U. S. Atomic Energy Commission.

[1] Keesom, Lark-Horovitz, and Pearlman, Science **116**, 630 (1952).

T14. Irradiation Induced Photoconductivity in Magnesium Oxide.* Harold R. Day,† *University of Missouri.*—Photoconductivity in single crystals of magnesium oxide was measured by a dc method. The spectral distribution of photoconductivity is characterized by peaks at 1.2, 2.1, 3.7, and 4.8 ev. Irradiation of the crystals by ultraviolet light causes an enhancement of the photoconductivity subsequently measured in the 1.2- and 2.1-ev bands. The enhancement effect reaches a saturation level which is independent of the intensity of the ultraviolet light and which is a measure of the density of imperfections in the crystal lattice. The ultraviolet activated region can be displaced by an electric field in such a direction as to indicate that the charge carriers are holes in the valence band. Neutron irradiation of the crystals gives rise to a thermally unstable enhancement of photoconductivity throughout the spectrum and also causes an increase in the level of saturation of the ultraviolet activation. The latter increase is stable at room temperature and indicates that the neutron irradiation produces new lattice defects. This effect saturates with increasing neutron flux. The density of lattice defects can be estimated from the photoconductivity. An energy level model is proposed.

* Work supported in part by the U. S. Office of Naval Research and a grant from R. C. A.

† Now at General Electric Research Laboratory, Schenectady, New York.

SATURDAY MORNING AT 11:00

Library, Assembly Room

TA. Business Session of the Southeastern Section

SATURDAY MORNING AT 10:00

Business Administration

(F. SEITZ presiding)

Invited Papers in Solid-State Physics

U1. Studies of the Tensile Strengths and the Adhesion of Metals by Means of High Centrifugal Fields. J. W. BEAMS, *University of Virginia.* (30 min.)

U2. Theoretical and Experimental Studies of Electronic Phenomena in Graphite. W. P. EATHERLY, *North American Aviation.* (40 min.)

U3. The Minimum in Electrical Resistance of Metals at Low Temperatures. E. MENDOZA, *Carnegie Institute of Technology.* (30 min.)

Business Meeting of the Division of Solid-State Physics

SATURDAY AFTERNOON AT 2:00

Business Administration

(J. W. BEAMS presiding)

Invited Papers in Solid-State Physics

V1. Possibilities of X-Ray Small-Angle Scattering for Study of Crystal Imperfections. A. GUINIER, *Universite de Paris.* (30 min.)

V2. Theory of Conduction-Electron Spin Resonance. CHARLES KITTEL, *University of California.* (30 min.)

V3. Thermodynamics of Irreversible Processes. H. B. CALLEN, *University of Pennsylvania.* (35 min.)

V4. The 1952 NRC Conference on the Nature and Properties of Surfaces of Solids. HARVEY BROOKS, *Harvard University.* (25 min.)

SATURDAY AFTERNOON AT 2:00

Bingham Hall

(A. E. RUARK presiding)

X-Rays; Scattering; Theoretical Physics

W1. Determination of an X-Ray Spectrum from Absorption Measurements by Laplace Transformation.* JUDITH CASSIDY GURSKY AND P. K. S. WANG, *Vanderbilt University.*—The attenuation of the beam from a 50-kv beryllium-window x-ray tube has been measured in aluminum and carbon. This information is used to determine the spectrum of the beam. The transmitted intensity I_x as a function of the absorber thickness x is given by[1]

$$\frac{I_x}{I_0}=\int_{\lambda_0}^{\infty} e^{-\mu(\lambda)x} f(\lambda)\,d\lambda,$$

where $f(\lambda)$ is the fractional intensity of the primary beam. $\mu(\lambda)$ being given, $f(\lambda)$ may be obtained by a simple change of variable if I_x/I_0 is known. The inverse Laplace transform of $(I_x/I_0)e^{\mu_0 x}$ leads directly to $f(\lambda)$ where μ_0 is the attenuation coefficient of the shortest wavelength λ_0. The practical problem lies in fitting an analytic expression to the experimental curve I_x/I_0 *vs* x. The spectra obtained from different fits and their comparison with the theory[2] will be presented.

* This work was supported, in part, by the U. S. Atomic Energy Commission.

[1] J. A. Greening, Proc. Phys. Soc. (London) **A63**, 1231 (1950).
[2] H. A. Kramers, Phil. Mag. **46**, 836 (1923).

W2. Second-Order Scattering Correction in Neutron and X-Ray Diffraction.* GEORGE H. VINEYARD,† *Brookhaven National Laboratory.*—A calculation has been made to estimate the multiple scattering correction needed in x-ray and neutron diffraction structure determinations. The sample is assumed to be a plane slab and to consist of small elements scattering with random phases. The intensity of n-fold scattered radiation may be expressed in terms of iterated integrals. Second-order scattering has been explicitly evaluated, with the aid of an approximation valid when the single scattering from each element is distributed nearly equally in a number of direc-

tions, as is usually the case with liquids and crystalline powders. Universal curves have been computed for several experimental arrangements. Some features which emerge are: (a) In all cases the ratio of 2nd-order to 1st-order scattering is proportional to the ratio scattering cross section/scattering plus absorption cross sections. For this reason multiple scattering is generally more important with neutrons than with x-rays. (b) In transmission arrangements the 2nd-order scattering is nearly isotropic for all scattering angles appreciably lower than 180°. (c) So long as 2nd-order scattering is small compared to 1st-order, 2nd-order is sufficiently representative of all multiple scattering.

* Under contract with the U. S. Atomic Energy Commission.
† On leave from the University of Missouri.

W3. Spin-Relativistic Effects in the Multiple Scattering of Electrons.* L. V. SPENCER AND C. H. BLANCHARD, *National Bureau of Standards.*—The slowly convergent Legendre polynomial series representing the angular distribution of electrons which have undergone multiple elastic scattering in traveling a given distance in a material has previously[1] been evaluated assuming a Rutherford single-scattering across section with a correction for screening at small angles; and, usually, using a small angle approximation. A new method[2] for summing Legendre polynomials permits evaluation taking account of the spin-relativistic corrections[3] to the Rutherford cross section and without small angle approximation. The results show that the spin-relativistic correction greatly improves the agreement of the theory (particularly at larger angles) with the experiment of Hanson *et al.*[4] for a thin gold foil at 15.7 Mev. The various effects other than elastic scattering (especially inelastic scattering and energy loss), and also the error involved in identifying foil thickness with pathlength will be discussed.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Moliere, Z. Naturforsch. **3A**, 78 (1948). Snyder and Scott, Phys. Rev. **76**, 220 (1949).
[2] Spencer, Phys. Rev. (to be published).
[3] Feshbach, Phys. Rev. **88**, 295 (1952).
[4] Phys. Rev. **84**, 634 (1951).

W4. Energy Spectrum Resulting From Electron Slowing-Down.* U. FANO AND L. V. SPENCER, *National Bureau of Standards.*—Given a uniformly distributed source of electrons of energy E_0, we wish to calculate the flux $y(E_0, E)dE$ of electrons of energy E traversing a small unit spherical probe. The distribution of energy losses ϵ is very skew, with an ϵ^{-2} tail further extended by bremsstrahlung. This precludes a continuous-slowing-down model (according to which y is the reciprocal stopping power) as well as the direct integration which works for x-rays.[1] An analytical Landau-type treatment, valid at all E_0, yields

$$y(E_0, E) = (mv^2/2\pi NZe^4)\int_0^\infty du \exp(-u)\tan^{-1} \times\{\pi/\log[1.5262(E_0-E)/Q_{\min}u]\},$$

where the symbols have their standard meaning and $Q_{\min}$ is the effective minimum permissible recoil energy. The integral is essentially an average reciprocal stopping number with slowly varying value$\sim$0.1. The analytical treatment breaks down as E decreases, when departures from the assumptions of a constant $Q_{\min}$ and of an ϵ^{-2} tail can no longer be disregarded. Here one can switch to a numerical procedure, akin to that for x-rays, which takes into account analytically the singularity of the cross section for $\epsilon\sim 0$.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] P. R. Karr and J. C. Lamkin, Phys. Rev. **76**, 1843 (1949).

W5. Methods for Calculating Approximate Cross Sections for Electron-Scattering. WILLIAM J. BYATT, *University of Alabama* (introduced by Arthur E. Ruark).—In computing differential cross sections for electron scattering, either by the Born approximation or the much-improved method of Montroll, Hart, and Greenberg, it is very helpful to start with a simple closed formula for the potential of the scattering atom. The scattering of electrons by He, Ne, A, and Hg is discussed. The Hartree fields of these elements are represented analytically; and the differential cross section is considered for electron energies from 100 ev to 1 Mev. Extension of the method to intermediate atomic numbers is simple in principle, but actual application in this domain must await computation of a few Hartree potentials in the region Z equals 30 to 70.

W6. Nyquist and Einstein Relations Derived from a Scattering Model. STEFAN MACHLUP, *Bell Telephone Laboratories.*—The Nyquist relation between electrical conductivity and thermal (Johnson) noise spectral density, and the Einstein (-Nernst-Townsend) relation between mobility and diffusion coefficient are classically derived by thermodynamic reasoning (equipartition). Therefore any microscopic model of a conductor which permits calculation of these quantities must also lead to the proper relations between them. It was thought that verifying the relations for a particular model (scattering of electrons in a crystal) may help in gaining insight into the model. The model must, of course, be statistical: scattering (e.g., by lattice vibrations, impurities) is a random process. If interactions between electrons are neglected, a model is completely determined by specification of both (1) electron distribution function f and (2) transition proabilities. From the latter one obtains a relaxation time τ for each electron state. One finds that the electron mobility, the thermal noise spectrum, and the electron diffusion coefficient are all proportional to the same functional of f and τ, making their ratios obey the classical relations.

W7. Energy Exchange in Molecular Collisions. B. WIDOM* AND S. H. BAUER, *Cornell University.*—It is shown that the semiclassical theory[1] of inelastic molecular collisions is an adequate approximation to the quantum-mechanical theory[2] when the relative translational energy of the colliding molecules is much greater than the change in internal energy. The semiclassical theory, however, fails in the neighborhood of the threshold. The average cross section for de-excitation collisions between carbon-dioxide and water is known[3] to have a maximum at about 350°K; its falling at higher temperatures has hitherto been considered an anomaly. When applied to this system, the semiclassical theory yields an effective collision diameter which is indeed a monotonically decreasing function of the temperature, this behavior being a direct consequence of the mutual reactivity of these molecules. When corrected for the low energy failure of the theory, the calculated collision diameter must also fall at low temperatures. The results are then in qualitative accord with the experimental facts over the whole temperature range.

* Now at University of North Carolina.
[1] C. Zener, Phys. Rev. **38**, 277 (1931).
[2] C. Zener, Phys. Rev. **37**, 556 (1931).
[3] A. Eucken and L. Küchler, Physiks Z. **39**, 831 (1938).

W8. On the Energy-Momentum Tensor of the Electromagnetic Field Inside Matter. N. L. BALAZS, *Dublin Institute for Advanced Studies** (introduced by Eric Rodgers).—Two different energy-momentum tensors have been proposed to describe the electromagnetic field inside matter. Abraham suggested a symmetric tensor while Minkowski's tensor is nonsymmetric. With the aid of a thought-experiment it is shown here that only the symmetric tensor satisfies the momentum conservation and center-of-mass theorems simultaneously.

* Now at University of Alabama.

W9. Nuclear Shell Structure as a Many-Body Phenomenon.* INGRAM BLOCH AND YÜ-CHANG HSIEH, *Vanderbilt University.*—A nuclear Hamiltonian containing pairwise

Hooke's law interactions between the nucleons[1] provides a first approximation to many-body nuclear theory. The normal-mode oscillators obey a more restrictive exclusion principle than that which applies to individual nucleons. The ground-state energy of one set of oscillators depends on the number of neutrons present, while that of another set depends on the number of protons present. The magic numbers have not emerged from the simple Hamiltonian described, but may be derivable from a refined Hamiltonian.

* Assisted by the U. S. Army Office of Ordnance Research and by the Carnegie Foundation for the Advancement of Teaching.

[1] W. V. Houston, Phys. Rev. **47**, 942 (1935); **49**, 206 (1936). For other references, see H. Margenau and K. G. Carroll, Phys. Rev. **54**, 705 (1938).

W10. Magic Numbers and the Statistical Model of the Nucleus.* H. W. NEWSON, *Duke University*, AND E. MERZBACHER, *University of North Carolina*.—While the Fermi gas model of the nucleus is well known to predict the general features of energy level densities in fairly excited nuclei, particularly their dependence on excitation energy and particle number, it fails, of course, to describe such details as the observed increase in the average level spacing in compound nuclei near neutron magic numbers. In an attempt to incorporate some effects of shell structure into the scheme of individual particle energy levels, which the nucleons of the gas can occupy, a "semiconductor" model for the nucleus was considered. The following sequence of individual particle energy levels was assumed: A low-lying n-fold degenerate level, separated by an adjustable gap from the set of energy levels of a free particle confined to the nuclear volume, where, however, the levels immediately above the gap are as dense as those near the Fermi energy in the conventional model. Calculations for low temperatures were made, and the entropy *versus* excitation energy was plotted for various sizes of the gap. Several ways of correlating the variables in the model with characteristic nuclear quantities will be discussed in the light of the empirical evidence. about level spacings.

* Under contract with the U. S. Atomic Energy Commission.

W11. On the Statistical Theory of Nuclear Reactions. BERNARD L. COHEN, *Oak Ridge National Laboratory*.—If Weisskopf's expression for the energy distribution, $N(E)$, of particles emitted from nuclear reactions which proceed via a compound nucleus is generalized by dropping his assumption that the sticking probability, η, for the inverse reaction is independent of energy, one obtains $1/\Sigma(E, E_0) = -\partial \log\eta/\partial E + 1/T(E_0-E)$ where $\Sigma = \{-\partial/\partial E(\log N(E)/E)\}^{-1}$, the slope of the energy spectrum as usually plotted. The following evidence is cited to show that the $-\partial \log\eta/\partial E$ term (hereafter (A)) is not negligible: (a) all observed neutron and proton ($E \gg$ Coulomb barrier) energy spectra curve away from the axis whereas assuming (A) $=0$ demands curvature toward the axis; (b) comparing these observed spectra shows that Σ is definitely not a function of (E_0-E) alone; (c) the values of (A) required to remove the large discrepancies between observed and calculated (n, p) and (n, α) cross sections are roughly consistent with those obtained from the experimental energy spectra. Assuming (A) not ignorable means that selection rules operate to make transitions to low-lying levels excessively probable. It also demands that if excited nuclei could be bombarded, sticking probabilities would not be unity as they are when ground-state nuclei are bombarded.

W12. The Energy-Momentum Tensor in General Stream Electrodynamics. M. AVRAMY MELVIN, *Florida State University*.—Unnecessary use of the canonical formalism may hinder insight into the structure of a theory. This is exhibited in recent discussions of the energy-momentum tensor in the "new classical electrodynamics," where the final symmetrized tensor turns out to be the same for both the first and second theories of Dirac. It is also the same for the more general stream theory discussed by the author. The simple reason for this sameness is that the form of the energy-momentum tensor does not depend at all upon the gauge conditions which characterize the different theories; this tensor is a consequence only of applying to a fine-grained stream of corpuscles of mass μ, charge ϵ, *specific* concentration N (i.e., number of corpuscles contained *in a unit comoving volume*), and continuous differentiable 4-velocity field $u^\alpha = dy^\alpha/ds$ (1) the Lorentz force law (L) for the individual corpuscles, and (2) the Maxwell equations: (M_1) expressing the vanishing of the cyclical divergence $\{A_{\alpha\beta,\gamma}+\text{cycl.}\}$ of the electromagnetic field $A_{\alpha\beta}$, and (M_2) equating the divergence $A^{\alpha\beta}{}_{,\beta}$ to the current density $N\epsilon u^\alpha$. The law of conservation of specific charge is as usual an identical consequence of (M_2). Assuming also $d\epsilon/ds = 0$, we have also (M_2') the vanishing of $(Nu^\alpha)_{,\alpha}$. The total specific force density is obtained upon multiplying (L) by N. Integrating this by parts and using (M_2') gives: $(N\mu u_\alpha u^\beta)_{,\beta} = (A_{\alpha\beta}A^{\beta\gamma})_{,\gamma} - A^{\beta\gamma}A_{\alpha\beta,\gamma}$.

SATURDAY AFTERNOON AT 2:00

Venable Hall

(E. K. PLYLER presiding)

Ultraviolet Spectra; Theory of Molecular Structure; Mass Spectroscopy

X1. The Near Ultraviolet Absorption Spectrum of *p*-Difluorobenzene Vapor. C. DEWEY COOPER, *University of Georgia*.—The vapor absorption spectrum of *p*-difluorobenzene has been investigated in the 2900–2400A region with a Bausch and Lomb Littrow quartz spectrograph. Most of the bands are double with a separation of only 3 or 4 cm^{-1}. The 0,0 band is located at 36 843 cm^{-1}. Prominent bands on the violet side of this band are found to involve the excited state frequencies of 163, 409, 819, and 1250 cm^{-1}. Both the 819 and 1250 frequencies are found in progressions. Weak, temperature dependent bands on the red side of the 0,0 band are found to involve the ground-state frequencies of 247, 452, 860, and 1260 cm^{-1}. In the *p*-difluorobenzene spectrum the 0,0 band is shifted 1246 cm^{-1} toward the red relative to the calculated 0,0 band of benzene. This shift will be compared with similar shifts for other mono- and di-substituted benzenes.

X2. A Correlation of the Infrared and Ultraviolet Spectra of Associated Alcohols.* GLADYS A. ANSLOW AND IRENE S. WHITE, *Smith College*.—To aid the interpretation of the ultraviolet absorption in alcohols, ascribed to $OH^+\cdots O$ and $OH\cdots O$ association,[1] freshly distilled specimens, showing no impurities in the infrared, have been investigated in the 3μ region with a Perkin-Elmer double-beam spectrometer and in the ultraviolet with a Beckman spectrophotometer; recording spectra at numerous concentrations in carbon tetrachloride and isooctane, respectively. Changes in the ratio of polymer to dimer components in the infrared were paralleled by corre-

sponding changes in the ultraviolet. Values of the monomer fraction α measured in the infrared permit the calculation of the degree of association f and the polymer length, also a correlation with the concentration c.[3] Specimens which indicate $OH^{+}\cdots O$ association in the uv obey the $F(\alpha, f, c)$ equations for polymers, and those indicating $OH\cdots O$ association indicate dimer association. Specimens which appear to be mixtures show similar spectral irregularities at concentrations at which monomerization proceeds rapidly.

* Supported by the U. S. Office of Naval Research and by the Research Corporation.
[1] Gladys A. Anslow *et al.*, Faraday Soc. Disc. No. 9, 299 (1950); Phys. Rev. **88**, 154 (1952).
[3] R. Me ke, Faraday Soc. Disc. No. 9, 161 (1950).

X3. The Near Ultraviolet Vapor Spectrum of Thianaphthene. R. C. HECKMAN* AND H. SPONER, *Duke University*.—The near ultraviolet vapor spectrum of thianaphthene has been photographed using the large and medium Hilger quartz spectrographs. The spectrum arises from two, possibly three electronic transitions. The 0,0 bands for these transitions have been assigned the frequencies 34 060 cm^{-1} (2935.2A), 38 300 cm^{-1} (2610A) [or possibly 38 240 cm^{-1} (2614A)] and tentatively 43 070 cm^{-1} (2320A). The first system exhibits sharp vibrational bands while bands in the other systems are diffuse. Correlations of vibrational differences with Raman lines have been established, particularly in the sharp system. A comparison has been made of the observed spectrum with the electronic band systems of naphthalene in the near ultraviolet.

* Charles F. Kettering Foundation Fellow.

X4. Electronic Energy Levels of Molecular Oxygen.* ALVIN MECKLER,† *M.I.T.*—A configuration interaction study of the lower-lying electronic energy levels of molecular oxygen has been made. With the 1*s* and 2*s* shells kept filled, the remaining eight electrons were distributed among the twelve spin-orbitals arising from the 2*p* levels on each atom. The molecular orbitals were formed as symmetrical linear combinations of the atomic orbitals, simply for convenience. Inclusion of all configurations implies complete equivalence of all possible constructions of linear combinations. Out of the 495 many-electron determinants a group of nine states of $^3\Sigma_g^-$ character was set up and twelve of $^1\Sigma_g^+$ character. The interaction matrix of each block was computed and diagonalized (by electronic computer) yielding excellent results for the triplet ground state, not as accurate ones for the lowest singlet. The energies and wave functions for the lowest triplet and singlet were calculated and compared for various values of internuclear separation. The history of the molecule is therefore correctly traced from infinite separation inward, revealing the competition between the magnetic and nonmagnetic states and the deviation from the single configuration approximation.

* Supported by the U. S. Office of Naval Research.
† Now a staff member of Lincoln Laboratory, M.I.T.

X5. A Molecular Orbital Treatment of the Contribution of the π-electrons to the Electric Dipole Moments of Some Phenyl Halides.* R. H. KNIPE, *Duke University* (introduced by H. Sponer).—The contribution of the π-electrons to the electric dipole moments of some mono- and di-halogenated benzenes has been treated by the molecular orbital method without overlap. The influence of the additional π-orbital brought into the system upon substitution of the halogen is studied by introducing semi-empirical parameters. Using the known bond lengths, the approximate additivity rule has been verified numerically for a range of values of the halogen Coulomb integral.

* Supported by the U. S. Office of Naval Research.

X6. Application of the Thomas-Fermi Method to the Calculation of Certain Molecular Vibration Frequencies. W. A. BOWERS, *University of North Carolina*.—An attempt has been made to use the Thomas-Fermi method to calculate the frequency of the "breathing" vibrations of tetrahedral and octahedral molecules. This is done by an extension of the calculations of March,[1] who regarded the nuclei of the outer atoms as smeared out over a spherical surface and applied the Thomas-Fermi method to the resulting spherically symmetric problem. The energy can then be calculated, and has a minimum as a function of sphere radius; hence bond length and vibration frequency, or force constant, can be found. The force constants found in this way have been compared with the experimental data for a number of tetra-halide molecules; the agreement is poor, as March found in the case of bond lengths, if the actual nuclear charges are used. However, by assigning effective nuclear charges to the atoms, corresponding to compression of the inner shells into the nucleus, a reasonable correlation with the data can be obtained.

[1] N. H. March, Proc. Cambridge Phil. Soc. **48**, 665 (1952).

X7. Determination of Molecular Weight of Organic Compounds by Mass Spectrometry. JOHN R. SITES AND BERNARD L. STREHLER, *Oak Ridge National Laboratory*.—An investigation is being undertaken to determine the molecular weights of some organic compounds essential to luminescence in the firefly lantern extract. Data will be presented which were obtained during preliminary observations on riboflavin, luciferesceine, and luciferin. The molecular weights of these compounds are less than 400.

X8. Mass Spectrometer Analysis of UO_2F_2 in UF_4. RUSSELL BALDOCK, JOHN R. SITES, L. O. GILPATRICK, AND HOWARD E. CARR,* *Oak Ridge National Laboratory*.—A time integration method has been developed for the quantitative analysis of UO_2F_2 contamination in UF_4. Data are collected from a sample held at constant temperature in the mass spectrometer until the sample is completely used up.

* Consultant, Alabama Polytechnic Institute.

SATURDAY AFTERNOON AT 2:00

Howell Hall

(W. C. DUNLAP, JR., presiding)

Semiconductors, III

Y1. The Electrical Resistance of Graphite at Low Temperatures.* H. W. HEMSTREET AND J. M. REYNOLDS, *Louisiana State University*.—Measurements, previously reported,[1] on the resistance of polycrystalline graphite, have been repeated with greater precision to allow extrapolation of the resistance to absolute zero temperature. These measurements were made on two samples over a range of temperature from room temperature down to 1.35°K. The resistance was found to increase smoothly as the temperature was lowered to about 20°K. At this temperature the resistance begins to level off

until at 4°K it is virtually temperature independent at a value about double the room temperature resistance. Below 4°K the resistance seems to fall slightly. From 3.5°K to 1.35°K the drop is about 0.1 percent where the probable error of each point is 0.025 percent.

* Supported by the National Science Foundation.
[1] H. W. Hemstreet and J. M. Reynolds, Phys. Rev. **87**, 178 (1952).

Y2. Thermoelectric Power of Carbons.* E. E. LOEBNER, *University of Buffalo.*—The thermoelectric power of various soft carbons has been previously investigated by the author at room temperature as a function of the heat-treatment temperature H. In this work measurements were performed with an improved technique at three temperatures T (a) 88°K, (b) 308°K, and (c) 573°K. A single batch of carbon rods was used, rods being heat-treated to progressively higher temperatures and investigated after each heat-treatment. The thermoelectric power and electric resistivity of these rods were determined at the three temperatures and plotted as a function of H. Each of the three curves for the thermoelectric power exhibits a shallow minimum (around 1300°C of H) and a maximum. The position of the maximum varies with the temperature of the sample: (a) 2180°C, (b) 2080°C, (c) 1990°C of H. The total variation of change in the power from the minimum to maximum is roughly proportional to the absolute temperature T, thus indicating a metallic behavior of an unfilled energy band for carbons in the baked range (1000°C $<$H$<$2000°C). All three resistivity curves show the well-known plateau:[1] the extent of the plateau varies with T, becoming shorter for higher T's, this being caused by a variation in the position of the high H end of the plateau.

* Supported in part by the U. S. Office of Naval Research.
[1] S. Mrozowski, Phys. Rev. **85**, 609 (1952) and **86**, 1056 (1952).

Y3. Electrical Properties of Indium Antimonide, InSb.* R. G. BRECKENRIDGE, W. R. HOSLER, AND W. OSHINSKY, *National Bureau of Standards.*—Measurements have been made of the electrical resistivity and Hall coefficient of indium antimonide, InSb, for a temperature range from liquid air to 200°C. This compound, whose physical properties strongly resemble germanium, has been prepared by the vacuum melting of high purity indium and antimony. The material was found to be a semiconductor with a low resistivity of the order of $10^{-2}\Omega$ cm at room temperature, a low activation energy for intrinsic conduction, *ca* 0.4 ev; and a high mobility of charge carriers, ca. 2.1×10^4 cm²/volt sec, for electrons at room temperature. It has been possible to prepare both n- and p-type samples by control of the composition of the melt. An analysis has been made of the temperature variation of the charge carrier densities and mobilities obtained from the resistivity and Hall coefficient data for both p and n type samples.

* This work was supported by the U. S. Office of Ordnance Research.

Y4. Thermally Unstable Disorder in p-type Ge Produced by Fast Neutron Bombardment. J. H. CRAWFORD, JR., J. W. CLELAND, D. K. HOLMES, AND J. C. PIGG, *Oak Ridge National Laboratory.*—A number of P type Ge samples have been irradiated at a variety of temperatures in the low temperature facility in the graphite reactor. The conductivity of P type Ge decreases with bombardment over the low temperature range investigated (−90°C to −160°C) at an initial rate which is about one-half that of N type material over the same temperature range. Warming the samples to room temperature and recooling indicates that a major portion of the disorder introduced below −90°C either anneals out or rearranges to a form which radically modifies the nature of the electronic energy levels associated with the disorder. Warm-up experiments also show that there are at least two types of thermally unstable disorder produced energy levels. Material bombarded below −140°C shows an additional decrease in conductivity on warm-up until the temperature rises to about −120°C, after which continued warming causes an increase in conductivity. Material irradiated above −140°C shows only a conductivity increase on warming. The disorder introduced above −140°C appears to anneal out or rearrange by a first-order process.

Y5. The Surface Tension of Liquid Silicon and Germanium. PAUL H. KECK AND WENDELL VAN HORN, *Signal Corps Engineering Laboratory.*—The surface tensions of liquid silicon and germanium were determined using the drop weight method. It was found to be 600 dynes/cm for germanium and 720 dynes/cm for silicon at their freezing points. The parachors of the group IVb elements as derived from surface tension measurements of the molten elements are compared with the atomic parachors calculated from compounds. The differences are interpreted as structural parachors which indicate that the bonding between neighboring atoms in the liquid state increase in nearly uniform steps from lead to germanium. Molten germanium and silicon have nearly the same structural parachor indicating similar structures which probably consist of tetrahedral groups of atoms.

Y6. Electrical Properties of Carbon Bisulfate Compounds. E. A. KMETKO, *University of Buffalo.*—The conductivity of graphite is known to be increased when bisulfate ions are introduced between the aromatic layers, this being due to formation of holes in the normally full π-band of graphite.[1] Results of an investigation of similar compounds using substances ranging from baked carbons to polycrystalline graphite will be reported. Baked carbons exhibit little change in conductivity and thermoelectric effect when bisulfate ions are introduced. Changes are increasingly larger for carbons heat-treated to higher temperature. For instance, the initial rate of change of resistance with ion concentration is for polycrystalline graphite (3000°C) 6 times greater than for a carbon baked to 1400°C. Baked carbons possess many traps on the crystallite boundaries (free carbon valencies)[2] which create large numbers of excess holes in the π-band of the pure material. Thus addition of a small number of extra holes by the formation of the compound changes only slightly the electronic properties of the substance. The number of traps is so large in baked carbons that the Fermi level is depressed below the inflection curve and the Hall coefficient is negative for these materials.

[1] G. R. Hennig, J. Chem. Phys. **19**, 922 (1951).
[2] S. Mrozowski, Phys. Rev. **85**, 609 (1952) and **86**, 1056 (1952).

Y7. Electrical Properties of the Compound Aluminum Antimony. R. K. WILLARDSON, A. C. BEER, AND A. E. MIDDLETON, *Battelle Memorial Institute.*—Preliminary investigations of the electrical properties of aluminum antimony indicate electrical characteristics somewhat similar to those reported for silicon with impurity additions. High purity aluminum and specially refined antimony* were reacted in approximately stoichiometric proportions to form the compound AlSb. The material was then processed to obtain specimens containing active impurities varying from approximately 0.5 percent to less than one part in ten million. Measurements were made of electrical resistivity, thermoelectric power, and Hall voltage over the temperature range from 90°K to 1200°K. Extrinsic conductivity of both n- and p-types was observed. The intrinsic conductivity indicated an energy band separation somewhat greater than that of silicon. The mobilities of the positive holes in the polycrystalline specimens of lower carrier density are given by $5\times10^6T^{-1}$ cm²/volt-second at the

higher temperatures where lattice scattering predominates. The effect of scattering by ionized impurities became significant at lower temperatures, the maximum of the mobility *versus* temperature curve occurring below room temperature.

* Supplied by Bradley Minjng Company, San Francisco, California.

Y8. The Magnetoresistance Effect in InSb. M. TANENBAUM AND G. L. PEARSON, *Bell Telephone Laboratories.*—H. Welker[1] has shown that the compound indium antimonide is a semiconducting material having properties akin to the fourth column elements germanium and silicon and that it has unusually high electron and hole mobilities. The preparation of this compound in a highly purified form through the use of zone-melting techniques[2] will be described. Polycrystalline specimens of 0.03 ohm cm resistivity are obtained. These are *n*-type at room temperature and change to *p*-type near 175°K. Magnetoresistance measurements with H perpendicular to I give $\Delta\rho/\rho = 8\times10^{-9}H^2$ which corresponds to an electron mobility of 15 000 cm²/volt-sec. Welker has reported Hall mobilities as high as 25 000 cm²/volt-sec. The magnetoresistance effect approaches zero for H parallel to I thus indicating spherical energy surfaces. This is in contrast to measurements in *n*-type germanium where a nonspherical shape of the energy surface has been proposed[3] to explain the results.

[1] H. Welker, Z. Naturforsch. **7a**, 744 (1952).
[2] W. G. Pfann, J. Metals **4**, 747 (1952).
[3] W. Shockely, Phys. Rev. **78**, 173 (1950); Phys. Rev. **79**, 191 (1950).

Y9. Hall Mobility in Insulation Photoconductors.* ALFRED G. REDFIELD,† *University of Illinois.*—A technique has been developed for measurement of the electronic Hall mobility in insulating photoconductors which avoids difficulties caused by space charge effects and crystal nonuniformities. The crystal is illuminated by short bursts of light so that negligible space charge is built up during the time of illumination. The Hall electrodes are of unconventional design. Preliminary results on several diamonds between 100 and 300°K fail to give a unique value of the mobility, possibly because of variation in impurity content from diamond to diamond. The room temperature electronic Hall mobility in diamond is evidently in qualitative agreement with previous[1] Hall mobility measurements and much lower than the value of drift mobility obtained by Pearlstein and Sutton.[2]

* Partially supported by the U. S. Office of Naval Research.
† U. S. Atomic Energy Commission predoctoral fellow.
[1] C. C. Klick and R. J. Maurer, Phys. Rev. **81**, 124 (1951).
[2] E. A. Pearlstein and R. B. Sutton, Phys. Rev. **79**, 907 (1950).

Y10. Preparation of Gray Tin Filaments. A. W. EWALD, *Northwestern University.*—Filaments of gray tin suitable for direct electrical measurements have been prepared, and the specific conductivity and the temperature dependence of the conductivity have been determined. The method of preparation consists in drawing fine wires of pure metallic tin in an inert atmosphere by the Taylor process.[1] After dissolving away the glass envelopes, the filaments are inoculated with gray tin powder and stored at a reduced temperature to allow the transformation to proceed. Interrupting the transformation when short segments of the gray modification have been produced facilitates making electrical contact through the adjoining metallic portions. Electrical conductivity measurements on five samples ranging in diameter from 50 to 200 microns and in length from 1 to 3 mm have yielded the values: $(2.25\pm0.05)\times10^{3}\Omega^{-1}$ cm^{-1} for the conductivity at 0°C and (0.088 ± 0.002) ev for the activation energy determining the temperature dependence in the intrinsic range. These results are in satisfactory agreement with those of Busch, Wieland and Zoller[2] obtained by eddy current loss measurements on gray tin powder.

[1] G. F. Taylor, Phys. Rev. **23**, 655 (1924).
[2] Busch, Wieland, and Zoller, Helv. Phys. Acta **24** (No. 1), 49 (1951).

SATURDAY AFTERNOON AT 2:00

Phillips Hall

(ERIC RODGERS presiding)

Solid-State Physics, Including Diffusion

(Papers Z1 to Z8 grouped together by request)

Z1. X-Ray Study of Graphitization. J. C. BOWMAN, *National Carbon Company* AND S. HAYES AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—The so-called carbons are highly imperfect structures which on annealing can be gradually transformed into graphites of various degrees of perfection. This process of graphitization in carbons, heated for very short time in the range between 1600 and 2000°C, has been studied by means of high resolution small angle x-ray scattering and by means of x-ray diffraction. In the range of angles between 10 and 30 minutes the small angle scattering indicates a total increase of about 40 percent in the number of particles in the range between 100 and 200A. This growth is accompanied by a substantial decrease of the number of small particles which scatter at higher angles. Diffraction patterns indicate a parallel increase in the average particle size in the *c*-direction from about 90A to 240A. A proposed mechanism of growth will be discussed.

Z2. Small Angle-X-Ray Scattering in Proton-Irradiated Diamond.* S. HAYES AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—Study of irradiation effects is particularly convenient in diamond because the high stability of the lattice minimizes annealing of the effects at room temperature. Natural uncut diamonds in form of thin plates, obtained through courtesy of the Koebel Diamond Tool Company, were irradiated by 360-Mev protons in the Carnegie Institute of Technology synchrocyclotron and the small angle x-ray scattering on irradiated and unirradiated crystals was compared by means of a high resolution instrument. Preliminary results indicate an appreciable increase of scattering in the range of angles between 10 and 30 minutes. No appreciable coloring was observed.

* Supported by a U. S. Atomic Energy Commission contract.

Z3. Changes in Conductivity of NaCl Produced by Bombardment with 360-Mev Protons.* E. A. PEARLSTEIN, *Carnegie Institute of Technology.*—Single crystals of NaCl, previously annealed in He at 650°C, have been irradiated with 360-Mev protons in the Carnegie Institute of Technology super synchrocyclotron. Amounts of bombardment were of the order of 10^{15}/cm². Large decreases in electrical conductivity were found, in agreement with the work of Nelson, Sproull,

and Caswell[1] on KCl. Much of this decrease annealed out at about 200°C in one hour. More annealing took place between 250°C and 300°C. No further annealing was observed up to about 470°C. After this annealing the conductivity measured between 100°C and 200°C was the same within 10 percent as in unirradiated crystals. The conductivity at higher temperatures could not be restored by annealing at temperatures up to about 470°C. Data will be presented on the magnitudes of conductivity and of irradiation. Calculations based on Seitz's work[2] indicate that each 360-Mev proton produces only about 3 sodium vacancies per cm of trajectory. This would lead one to believe that this flux of protons changes the conductivity mainly by producing ionization, except for the fact that the change does not completely anneal with regard to the temperature dependence of the conductivity.

* Supported by a U. S. Atomic Energy Commission contract.
[1] Nelson, Sproull, and Caswell, Bull. Am. Phys. Soc. **28**, No. 1 (1953).
[2] F. Seitz, Disc. Faraday Soc. No. 5, 271 (1949).

Z4. Density Change in Proton Irradiated Potassium Chloride.* W. J. LEIVO, *Carnegie Institute of Technology.*—Single crystals of potassium chloride were irradiated with about 10^{16} per cm² 360-Mev protons in the Carnegie Institute of Technology synchrocyclotron. The irradiation was fairly uniform as evidenced by color centers which were produced throughout the interior of the crystal. The change in density of the crystals upon irradiation was measured and it was found that the crystals decreased in density. This change in density was determined by observing the difference in suspension temperatures of the crystals when suspended in 1,3-dibromo-propane. To prevent burning of the crystals and contamination of the surface during irradiation, the crystals were enclosed in a thin-walled aluminum container which was filled with helium. An exposure of one hour in the proton beam produced a decrease in density of 5×10^{-5} g/cm³ which is large compared to theoretical expectations.

* Supported by a U. S. Atomic Energy Commission contract.

Z5. Mechanical Properties of Proton Irradiated Alkali Halides.* W. H. VAUGHAN, W. J. LEIVO, AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—The elastic and plastic behavior of single crystals of potassium chloride which were subjected to proton bombardment in the Carnegie Institute of Technology 360-Mev synchrocyclotron was determined by bending. The crystals were loaded at their midpoint while being freely supported at their ends and the maximum deflection as a function of the load was measured giving the Young's modulus and the elastic limit. Crystals which were irradiated for one hour in the cyclotron were compared with unirradiated crystals having the same dimensions. Preliminary results indicate an increase of Young's modulus. Hardness of irradiated and of unirradiated single crystals of KCl and of NaCl was measured by a Tukon tester which made indentations about 10^{-3} mm deep. Irradiation increased the hardness of the surface of the crystals (for NaCl from 16.3 to 36 while) the hardness of the inside of the crystals as measured on cleaved irradiated samples. Surface hardness increased with increasing beam intensity.

* Supported by a U. S. Atomic Energy Commission contract.

Z6. On Change of Metallic Conductivity Through Change in Thermal Scattering.* R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—In many changes of electrical conductivity observed in metals, the effect can be interpreted in terms of changed periodicity of the lattice or as a result of introduction of imperfections. The first occurs, for instance, in ordering phenomena, the latter in irradiation by nucleons. However, both these changes may be accompanied by a change in the vibration spectrum of the lattice and thus by a change in the thermal scattering of the conduction electrons. A rough estimate of these changes in ordering and in irradiation effects is given and the results compared with experimental data.

* Supported by a U. S. Atomic Energy Commission contract.

Z7. Anisotropy of Grain Boundary Diffusion.* L. COULING AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—As a result of a study of diffusion of silver and of zinc in grain boundaries of copper, a definite structure of these boundaries has been proposed.[1] In particular in grain boundaries between grains having one cubic direction in common and the angle θ between the other cubic directions varying from about 15 to 35 degrees the diffusion would occur along "rods" of distorted lattice caused by clustering of dislocations (or high concentration of vacancies). This would lead to an anisotropy of diffusion in various directions in the boundary. Diffusion in directions forming an angle $\varphi=0$, 45, and 90° with the common cubic direction has been measured using radioactive silver and an autoradiographic technique on bi-crystals of copper. Early indications of anisotropy of diffusion have been confirmed for the above-mentioned range of θ while for θ near 45° little or no anisotropy has been found in accord with the model of a uniform and isotropic grain boundary.

* Supported by a U. S. Atomic Energy Commission contract.
[1] R. Smoluchowski, Phys. Rev. **87**, 482 (1952).

Z8. Grain Boundary Self-Diffusion in Body-Centered Lattice.* C. W. HAYNES AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—Pronounced grain boundary diffusion was previously observed in face-centered cubic lattices in which the difference between the close-packed inside of the grain and the distorted grain boundary material is presumably large. In body-centered lattices, this difference would be expected to be much smaller. Bi-crystals were grown by means of the strain-anneal technique in iron containing about 3 percent silicon (to promote growth of large crystals). The relative orientation of the crystals was predetermined by Dunn's "seed" method.[1] The crystals had a common [110] direction and an angle $5°\leqslant\theta\leqslant86°$ between the axes in the (110) plane. The specimens were plated on one side with Fe^{55} to about 5×10^{5} cpm, diffused at various temperatures between 804°C and 827°C, and the depth of penetration of the radioactive isotope determined by autoradiography and by counting. The results indicate absence of measurable grain boundary diffusion at angles up to about $\theta=20$ degrees and an increasing boundary penetration up to $\theta=85$ degrees. There appears to be a cusp in the neighborhood of $\theta=45°$.

* Supported by a U. S. Atomic Energy Commission contract.
[1] C. G. Dunn, J. Metals **1**, 72 (1949).

Z9. Diffusion of Antimony in Silver.* E. SONDER, L. SLIFKIN, AND D. LAZARUS, *University of Illinois.*—As part of a general program of investigating diffusion of various neighboring elements into silver, diffusion coefficients for antimony into single crystals of 99.99 percent pure silver have been measured over a temperature range of 500 to 940°C using Sb^{124} as a tracer. A least squares calculation yields $D=0.19\exp(-38\,500/RT)$ cm²/sec. This is consistent with tentative values reported earlier and confirms the sharp disagreement with the data of Seith and Peretti, who obtained $D=5\times10^{-5}\exp(-21\,700/RT)$ cm²/sec.[1] Experiments concerning grain boundary diffusion for Sb^{124} into silver will also be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Seith and Peretti, Z. Electrochem. **42**, 570 (1936).

Z10. Diffusion of Cadmium in Single Crystals of Silver.* T. TOMIZUKA, L. SLIFKIN, AND D. LAZARUS, *University of Illinois.*—As part of a program to obtain the dependence on atomic number of the diffusion in silver of neighboring elements, diffusion of cadmium 115 in 99.99 percent pure single

crystals of silver was measured. A thin wall beta-counter was employed for the immersion counting of a thin cylindrical layer of solution and the reproducibility thus obtained was satisfactory. Measurements at higher temperatures give a tentative value of 41 kcal/mole for the activation energy. This differs radically from the data of Seith and Peretti.[1] This will be compared with the activation energy of self-diffusion in silver[2] and with that of the diffusion of antimony in silver.[3]

* Supported in part by the U. S. Atomic Energy Commission.
[1] W. Seith and E. Peretti, Z. Elektrochem. **42**, 570 (1936).
[2] Slifkin, Lazarus, and Tomizuka, J. Appl. Phys. **23**, 1032 (1952).
[3] Slifkin, Lazarus, and Tomizuka, J. Appl. Phys. **23**, 1404 (1952).

Z11. The Influence of Impurities on Diffusion in Solids.* ALBERT W. OVERHAUSER, *University of Illinois.*—The elastic distortions introduced into a lattice by impurity atoms will modify the potential barriers over which atoms must jump during the diffusion process. A statistical distribution in barrier heights results which increases the average rate of diffusion by a factor e^{bf}, where f is the atomic fraction of impurity atoms and b is a constant. Diffusion by means of vacancies was assumed. The elastic strains about each impurity were estimated from the degree of misfit of the impurity atom. The change in barrier height at the saddle point due to a given distortion was assumed to be due to the change of the repulsive exchange potential of the nearest neighbors. A repulsive potential of the usual exponential type, fitted to the elastic constants, was used. An increase in the rate of self-diffusion has been observed for small amounts of Cu in Ag by Holloman and Turnbull, for Pb in Ag by Hoffman and Turnbull, for K^+ in NaCl by Etzel, and for interstitial Cu in Cu by the writer. The observed magnitudes for the coefficient b in each of the above cases are about 10, 10^2, $\frac{1}{2}\times10^3$, and 10^4, respectively, and agree with the computed values to a factor of two.

* This work was supported by the U. S. Atomic Energy Commission.

Z12. Activation Entropies for Diffusion Mechanisms.* H. B. HUNTINGTON, G. A. SHIRN, AND E. S. WAJDA, *Rensselaer Polytechnic Institute.*—For all diffusion mechanisms there are associated changes in the entropy associated with the occurrence of the activated complex that affect the diffusion coefficient as $\exp(\Delta S/k)$. An effort has been made to estimate these quantities from a simple atomic model considering only the changes in the vibration spectrum caused by the lattice defect during the diffusion jump. The calculation has been applied to a fcc metal with long range cohesive forces and close-range exponential repulsion between ions. The changes in the atomic vibrations can be considered as arising mainly from the central repulsive forces and their effect on the entropy is calculated from the basis of an Einstein model. These local effects are somewhat offset by the changes in the medium far from the defect where the condition for zero surface pressure affects the solition of the spherical elastic defect. For some defects ΔS is negative contrary to current thinking by some workers. For the particular case of an interstitial defect (using a repulsive force law fitted to the elastic data of copper) ΔS was about $-4.3k$. The negative result arises from the high density at the defect. For a vacancy defect with the same model ΔS is about $+1k$.

* Supported by the U. S. Atomic Energy Commission.

SUPPLEMENTARY PROGRAMME

SP1. A Versatile Radiation Oven.*† RICHARD B. BELSER, *Georgia Institute of Technology.*—The construction of an economical, high temperature, infrared oven consisting of a one-liter beaker, lined with a reflecting material, and a single 250-watt, infrared bulb has been previously described.[1] This oven has been developed further into a more versatile tool. The position of the axes of the beaker and the lamp with reference to a horizontal axis is of little importance in the oven's efficiency. By operation of the oven, with the beaker inverted over the lamp, the placing of samples to be heated is facilitated. The oven may be powered by a photoflood lamp or ultraviolet sun lamp as well. It thus offers intense fields of visible or ultraviolet radiation. By using a lamp with a hole drilled in its face the oven may be operated within a vacuum chamber. The heating efficiency is greater within the vacuum. A temperature of 725°C was reached within the oven with 135 volts across the lamp's filament. By use of this oven as a heating agent, without and within a vacuum, some interesting studies of the "aging" of thin metal films have been made.

* Supported by U. S. Army Signal Corps.
† To be given at the end of Session I if the Chairman rules that time permits.
[1] The Research Engineer, Georgia Institute of Technology, January, 1952, p. 9.

SP2. A Phase Transition in $ND_4D_2AsO_4$.* † B. C. FRAZER, *Brookhaven National Laboratory.*—It was shown by Matthias[1] that, as in the case of KD_2PO_4,[2] $ND_4D_2PO_4$ has a transition temperature about 90° higher than the undeuterated salt (an increase from 148°K to 242°K). The transition temperature for $NH_4H_2AsO_4$ is 216°K, which suggests that deuteration should shift the transition above room temperature. This has been confirmed by dielectric and optical studies. The transition temperature observed was 31°C. Thus the shattering or cracking which has usually interfered with investigations below the transition temperatures of the ammonium salts can be avoided, since $ND_4D_2AsO_4$ crystals can be grown at room temperature directly in the orthorhombic phase. The preferential axis of growth was identified optically and by x-rays as being what becomes the tetragonal C axis in the transition. Measurements were made in the laboratory of Dr. Ray Pepinsky at the Pennsylvania State College.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
† To be given at the end of Session E if the chairman rules that time permits.
[1] B. T. Matthias, Phys. Rev. **85**, 141 (1952).
[2] W. Bautle, Helv. Phys. Acta **15**, 373 (1942).

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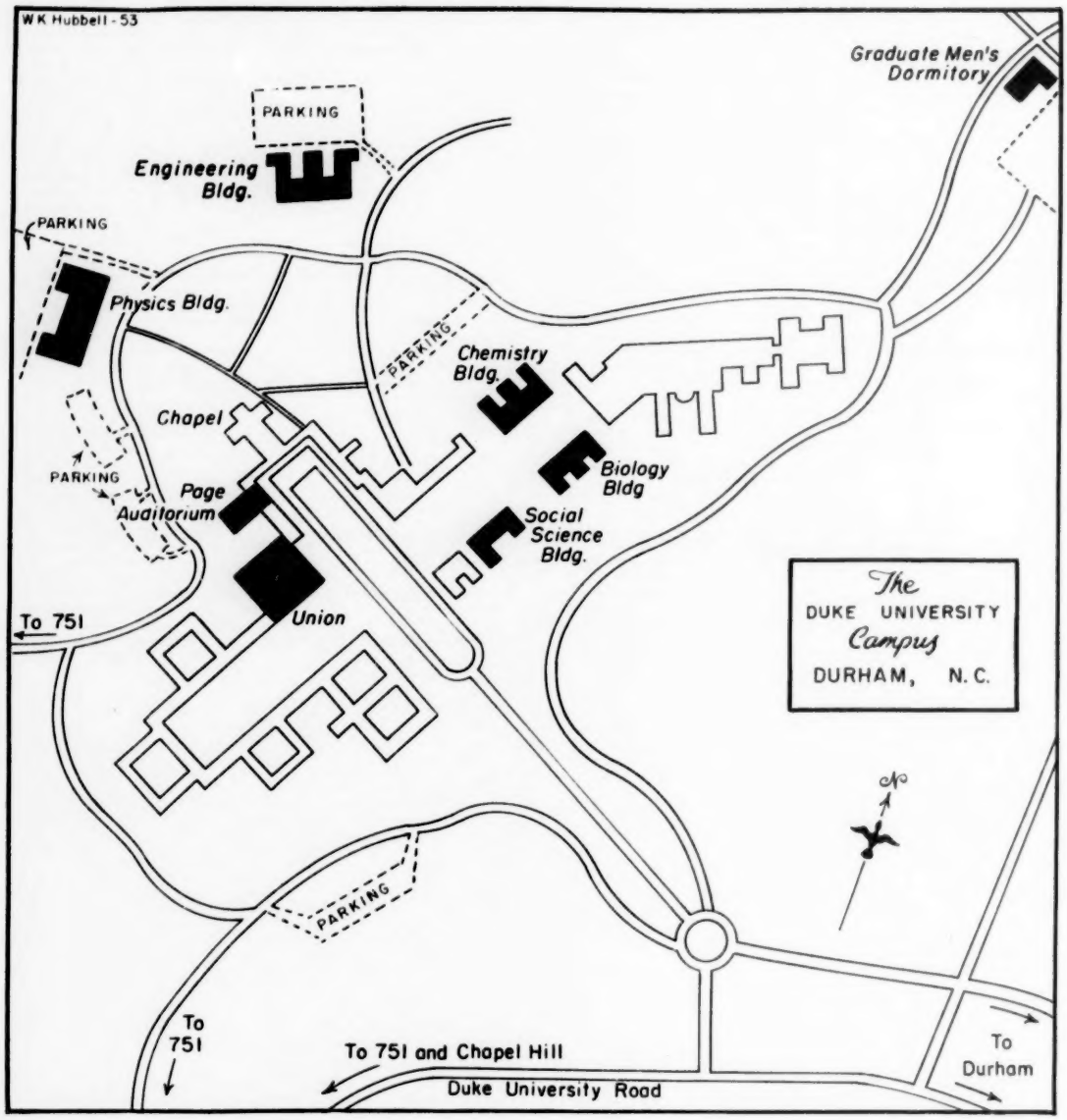
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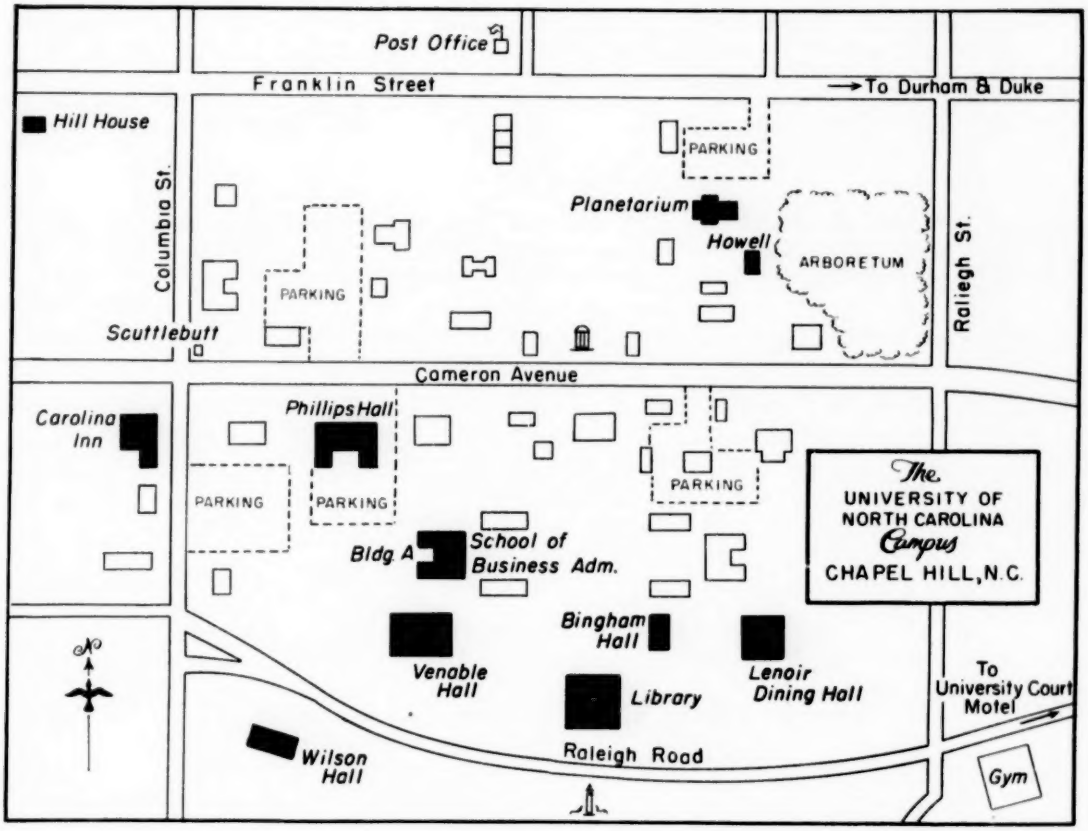
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